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GEOLOGY OF THE BEARPAW FORMATION IN SOUTH CENTRAL ALBERTA

by

© ANTOINE GHALI ELIA HABIB

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE
IN
GEOLOGY

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Supervisor

Pavlik

F. J. Hein

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Date. April 7 1981

ABSTRACT

A subsurface study of the Upper Cretaceous Bearpaw Formation using 668 borehole electric logs was carried out to map the subsurface distribution, geometry, lithologic variation and subdivisions of the formation in southcentral Alberta. Correlations between the interpreted fluctuations in water depths from lithology alone, from foraminifera and from other studies permitted interpretation of the depositional environment of the Bearpaw Formation in the study area.

In southcentral Alberta, six cycles of coarsening-upward deposits are recognized above the sands of the Judith River Formation. The Bearpaw Formation consists of the lower five of these cycles and the fine fraction of the uppermost sixth cycle. The coarse fraction of the sixth cycle forms the basal beds of the overlying Horseshoe Canyon Formation. The cycles are informally designated in ascending order as cycle A, B, C, D, E and F. Each cycle consists of a lower shale or silty shale unit which is overlain by a sandstone or sandy siltstone unit and the top of a cycle is often marked by the presence of a bentonitic clay which is overlain by a coal seam. The shale units of all cycles are generally thinner in the north and west and are wedge-shaped and relatively thick in the south and east of the study area. The sandstones of the Bearpaw Formation are thick along east-west trending channel-like features and the sands

are relatively thinner and sheet-like between the channels. All the units of the cycles can be traced over large distances across the area in the subsurface with the exception of the shales of cycle E and F that are not present in the western part of the study area.

Five major episodes of increase in water depths are indicated by the deposition of shales of cycle A, cycle C, cycle D, cycle E and cycle F of the Bearpaw Formation. Two minor fluctuations are suggested by the deposition of shales of cycle B and the shales at the base of the lower part of cycle D. The major fluctuations in water depth that occurred during the deposition of the Bearpaw Formation in southcentral Alberta are correlative with the five fluctuations that were recognized by Given (1969) and by Given and Wall (1971) from the profusion of calcareous foraminifera in these parts of the formation in the R.C.A. Castor Well.

Deposition of the Bearpaw Formation in southcentral Alberta took place in a relatively shallow marine deltaic environment which was associated with the movement of a shoreline westward and eastward across the area. The different deltaic subenvironments are represented by prodelta shales that grade into silts and sands of the delta front and distributary mouth bar facies and finally into coals of the swamp environment.

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The study of the subsurface geology of the Bearpaw Formation in southcentral Alberta was sponsored by the department of geology of the University of Alberta through Dr. G.D. Williams, and the author is indebted to both the department and Dr. Williams for their support.

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I. INTRODUCTION

Epicontinental seas flooded the western interior of North America several times during Late Cretaceous time. The last of these inundations deposited the Bearpaw Formation in Alberta and neighbouring areas of the interior.

Previous studies indicate that the Bearpaw was deposited in a single transgression-regression cycle during a period of advance and gradual retreat of the Bearpaw Sea over the area.

The western margins of this great seaway often retreated from the west as great masses of sediments were periodically eroded from youthful mountains and deposited along the shoreline. Partial withdrawal of the sea gave way to the formation of swamps and shallow environments where coal and shoreline sands were deposited. As the sea struggled back and forth, the influx of sediments progressively drove the waters gradually to the east, south and possibly north until finally the sea withdrew completely from the interior towards the end of the Cretaceous time, leaving only imprints of its existence.

A. Scope of the Study

The purpose of this work was to study the subsurface geology of the Bearpaw Formation in southcentral Alberta. The objectives can be detailed in point form as follows:

1. To correlate in detail the Bearpaw Formation in the

subsurface.

2. To delineate the geometry and distribution of the formation in the area of study.
3. To subdivide the Bearpaw Formation into individually mappable units on the basis of specific electric log signatures.
4. To relate the findings of this work to studies made in the surrounding areas.
5. To suggest a depositional model for the Bearpaw sediments.
6. To indicate the relative position of the shoreline during the deposition of each unit of the Bearpaw Formation.

B. Area of Study

The area under study lies between Calgary and Red Deer in southcentral Alberta, between Township 36 in the north and Township 25 in the south. Control is limited to the east by wells that were spudded in the lower Edmonton Group, as the upper part of the Bearpaw Formation is concealed by surface casing. The western limit of the study approximately follows the eastern limit of the disturbed belt where the inferred margin of the Bearpaw sea has been placed (figure 1). The study covers approximately 200 townships or 8,748 square miles (13,542 square kilometers).

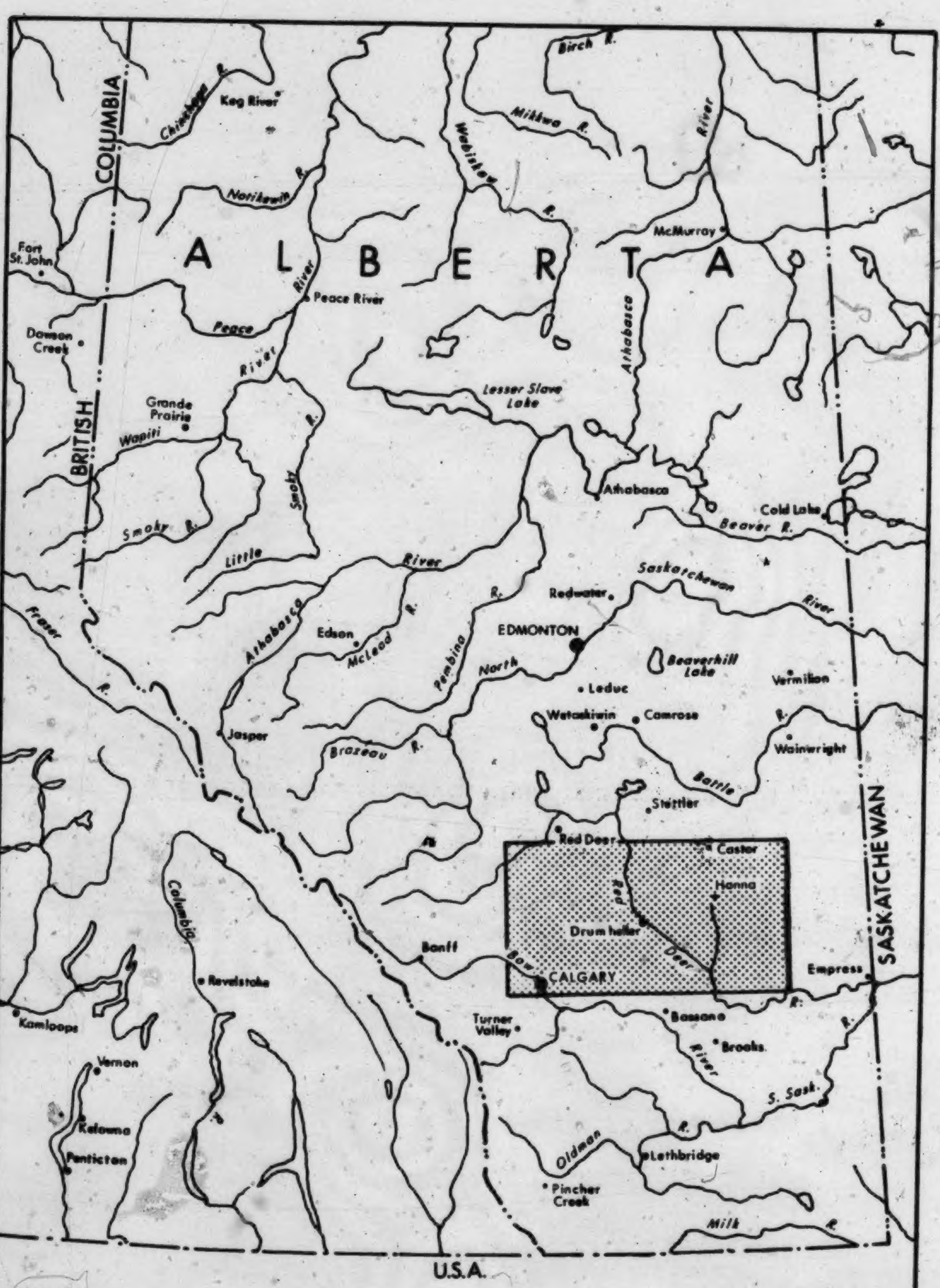

ALBERTA
BRITISH COLUMBIA
SASKATCHEWAN
U.S.A.
Birch R.
Keg River
Chinchaga R.
Mikkwa R.
Wabiskaw R.
River
Notikewin R.
McMurray
Fort St. John
Peace River
Peace River
Dawson Creek
Athabasca
Lesser Slave Lake
Grande Prairie
Wapiti
Smoky R.
Smoky R.
Little
Athabasca
Cold Lake
Beaver R.
Saskatchewan River
Redwater
Fraser R.
River
Athabasca
Edson
McLeod R.
Pembina R.
EDMONTON
North
Beaverhill Lake
Vermilion
Leduc
Wetaskiwin
Camrose
Jasper
Brazeau R.
Battle R.
Wainwright
Stettler
Red Deer
Castor
Hanna
Red Deer R.
Drumheller
Columbia
Banff
Bow
CALGARY
Empress
Revelstoke
Kamloops
Turner Valley
Bassano
Brooks
River
Vernon
S. Sask. R.
Kelowna
Penticton
Oldman R.
Lethbridge
Pincher Creek
Milk R.

Figure 1. Location map of the area of study.

▨

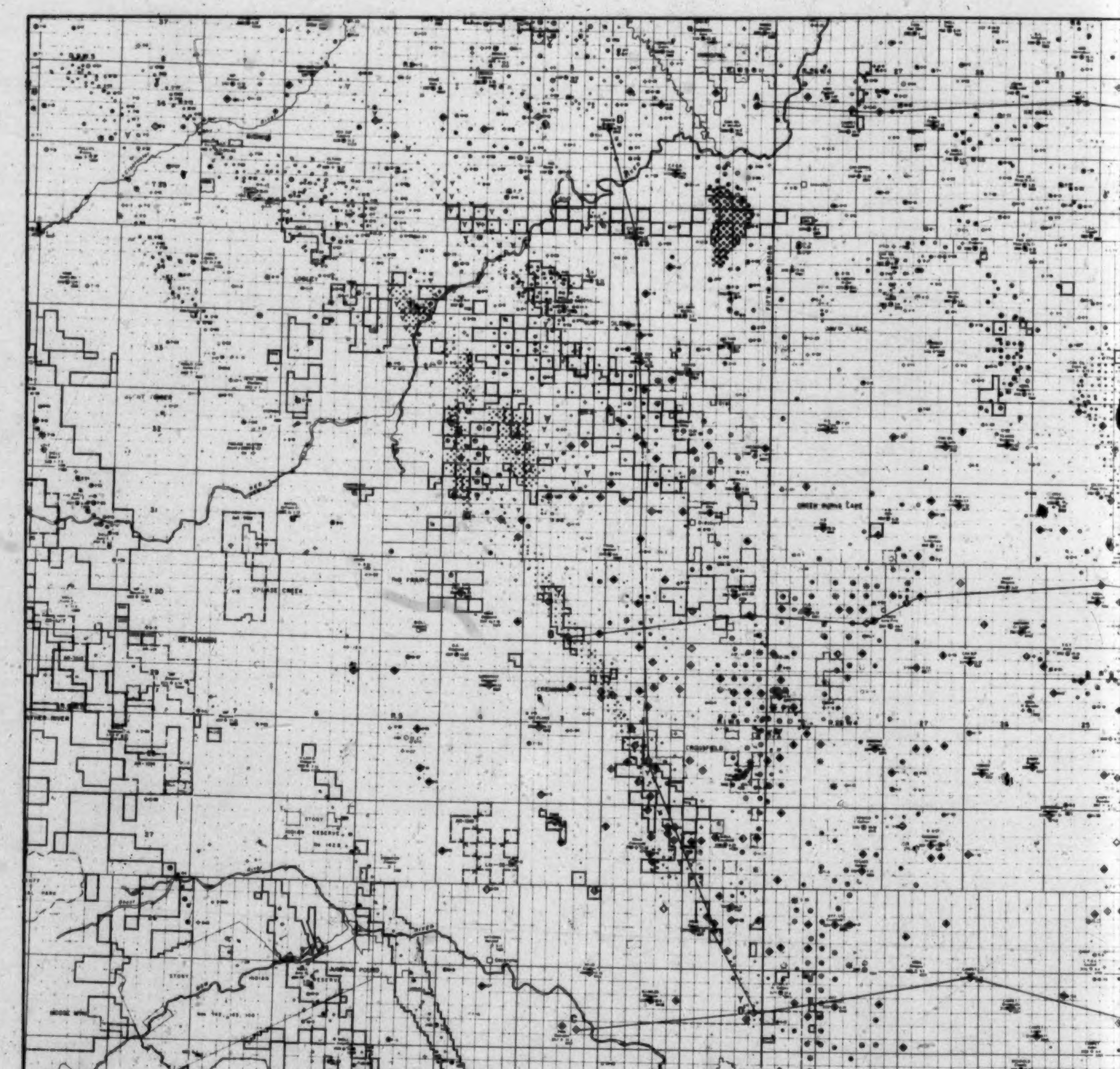
C. Method of Investigation

The major portion of information for the study was derived from geophysical borehole logs on microfilm from files of the Research Council of Alberta.

Electric logs were the major tool used in the study, supplemented by radiation and porosity logs. Electric logs from 668 boreholes were used for the detailed analysis of the formation (figure 2). Tops of the Colorado Shale, the Milk River Formation marker and the Lea Park Shale were picked for 324 wells and depths were recorded. The top of the Judith River Formation, the base of the Edmonton Group and tops of markers within the Bearpaw Formation were picked for the 668 wells studied and the depths were tabulated.

Electric logs from 324 boreholes were used to construct six detailed stratigraphic cross sections, utilizing a one to three miles spacing between individual wells along each cross section. Correlation was begun from a central point (Lsd. 5, Sec. 34, Twp. 30, Rge. 22, W. 4 Mer.) and was carried north, south, east, and west from that point.

The secondary phase commenced by using control points already established and correlating back in a loop in an attempt to close the loop. Five township (30 miles) spacing was used between cross sections running east to west that is, along Township 25, Township 30, and Township 36. North to south cross sections were constructed along Range 2 west of the Fifth Meridian, and Ranges 22 and 19 west of the Fourth Meridian.



BENJAMIN
CROSSFIELD
CALGARY

1 OF

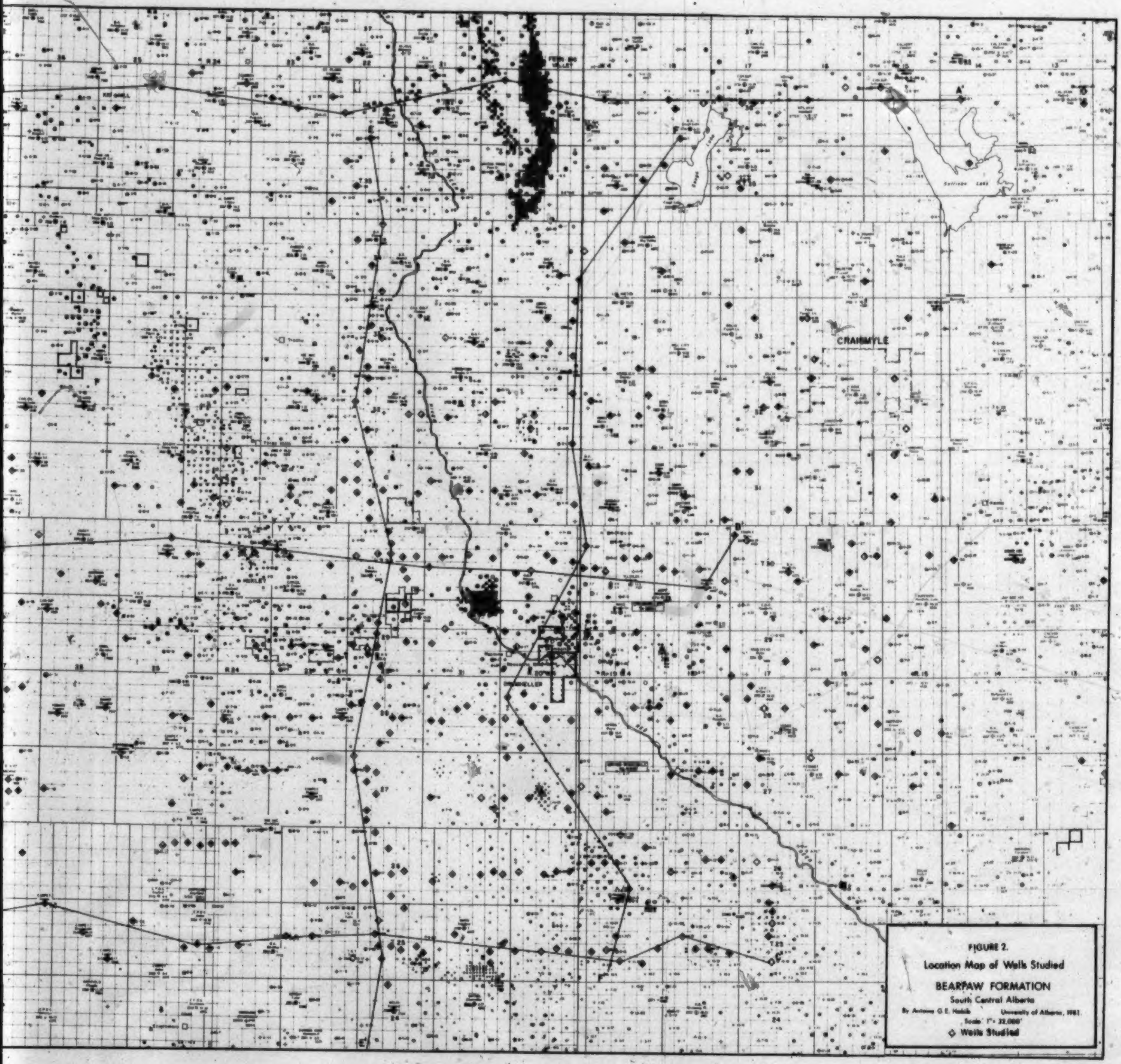

A'
B'
CRAIGMYLE
DRUMHELLER
T 30
R 24
Sullivan Lake

FIGURE 2.

Location Map of Wells Studied

BEARPAW FORMATION

South Central Alberta

By Antoine G.E. Habib University of Alberta, 1981.

Scale: 1" = 32,000'

◇ Wells Studied

2 OF 2

The final phase in the correlation established the link between the major cross sections. At this stage the markers established were picked in an east to west direction starting in Township 26, then carried north to Township 32 and to Township 36 east of Range 22 west of the Fourth Meridian.

II. GENERAL GEOLOGY

A. Previous Studies

The first delineation of the Bearpaw Formation was done by Hatcher and Stanton (1903) and Stanton and Hatcher (1905), in Montana. They named the formation for the Bearpaw Mountains where the shales are well exposed along the north, east and south slopes. They recognized that the formation extended into southern Alberta in the Cypress Hills where it was mapped by Canadian geologists (Dawson, 1882, 1884) as Pierre Shales (figure 3).

Dowling (1917) introduced the term, Bearpaw Shale, to Canadian literature in southern Alberta where the formation is well exposed along the banks of the Oldman River from Ryegrass flat to Piyami Coulee, and near the mouth of St. Mary River. Dowling listed the invertebrate fossils found in the formation and determined the thickness to be 622 feet (189.6 meters) in the area.

Williams and Dyer (1930) recognized the Bearpaw Shales along the creeks draining the north slopes of the Cypress Hills and along both flanks of the Sweet Grass Arch. Sands were reported within the lower part of the formation and a prominent sandstone marker was reported from the middle part of the unit to the north.

Detailed stratigraphy of the Bearpaw Formation in the Lethbridge area was presented by Link and Childerhose (1931), where the lower boundary of the shale is well marked

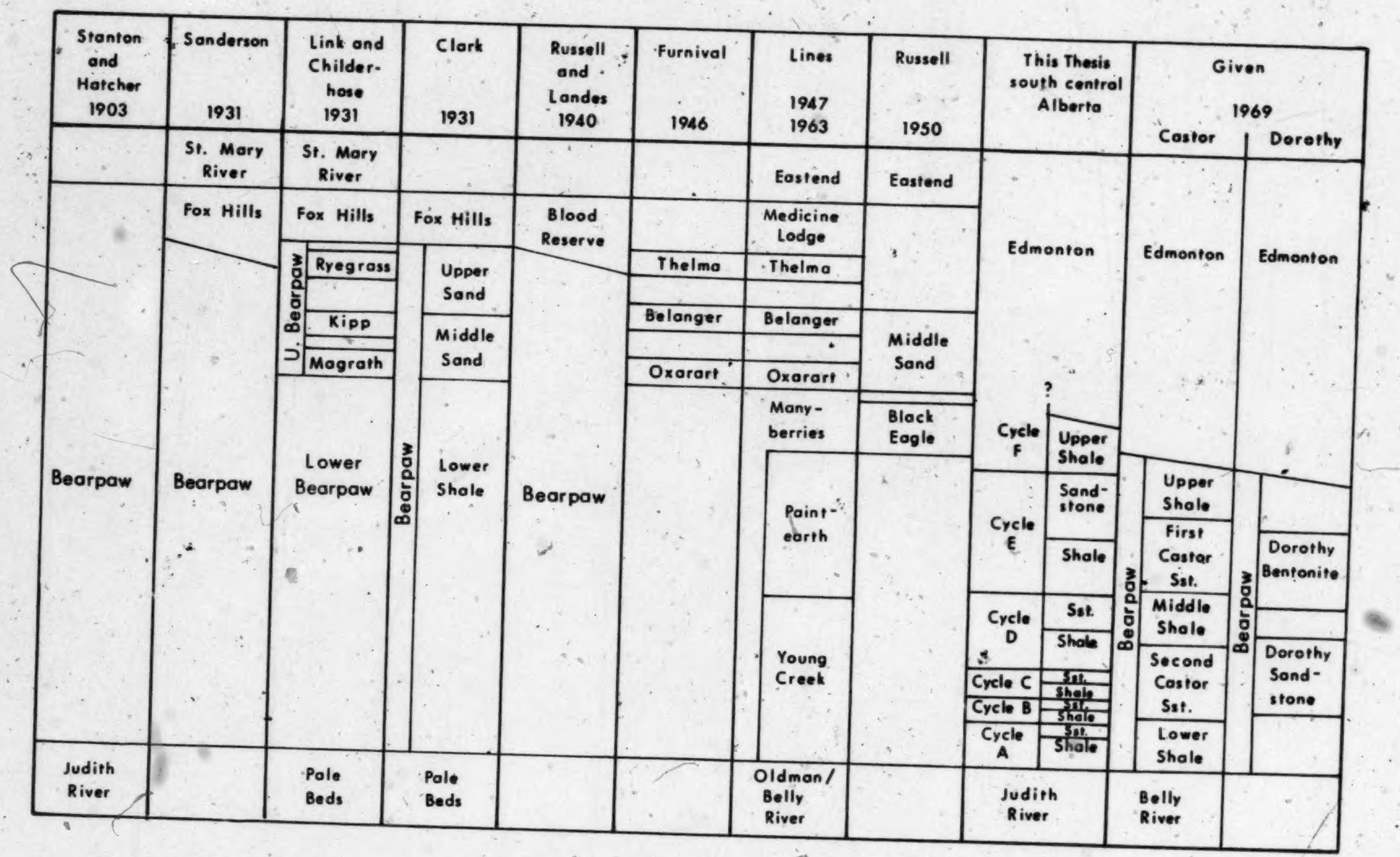

Stanton and Hatcher 1903
Bearpaw
Judith River
Sanderson 1931
St. Mary River
Fox Hills
Bearpaw
Link and Childerhose 1931
St. Mary River
Fox Hills
U. Bearpaw
Ryegrass
Kipp
Magrath
Lower Bearpaw
Pale Beds
Clark 1931
Fox Hills
Upper Sand
Middle Sand
Lower Shale
Bearpaw
Pale Beds
Russell and Landes 1940
Blood Reserve
Bearpaw
Furnival 1946
Thelma
Belanger
Oxarart
Lines 1947 1963
Eastend
Medicine Lodge
Thelma
Belanger
Oxarart
Many-berries
Paint-earth
Young Creek
Oldman/ Belly River
Russell 1950
Eastend
Middle Sand
Black Eagle
This Thesis south central Alberta
Edmonton
?
Cycle F
Upper Shale
Cycle E
Sand-stone
Shale
Cycle D
Sst.
Shale
Cycle C
Sst.
Shale
Cycle B
Sst.
Shale
Cycle A
Sst.
Shale
Judith River
Given 1969
Castor
Edmonton
Bearpaw
Upper Shale
First Castor Sst.
Middle Shale
Second Castor Sst.
Lower Shale
Belly River
Dorothy
Edmonton
Bearpaw
Dorothy Bentonite
Dorothy Sand-stone

Figure 3. Local terminology for the Bearpaw Formation.

by the Lethbridge coal measures of the upper part of the Belly River succession. Link and Childerhose subdivided the Formation into two parts namely "... the lower one-third, which is almost devoid of sands ..., and the upper two-thirds, containing three distinct sandstone members or zones, and lighter bluish or steel-gray, somewhat sandy, shales" (1931, p. 1231). The sandstone members are in ascending order the Magrath, Kipp and Ryegrass Sandstone members. Bentonite seams and limy ironstone concretions with numerous fossils were also described from the Formation.

A similar study was done by Clark (1931) between Keho Lake and Bassano in southern Alberta, in which he reported a thinning of 230 feet in the thickness of the Bearpaw Formation from Keho Lake in the south to Bassano in the north.

The name "Fox Hills" was proposed for the marine sandstone above what was then considered to be the Bearpaw Formation by Sanderson (1931). This sandstone lies immediately below the basal coal seam of the non-marine St. Mary River Formation in southern Alberta, and is considered to be a well sorted beach sand ranging in thickness from 31 to 327 feet south of the Bow River, thickening to the west. North of the Bow River the Fox Hills Formation could not be identified.

The thickness of the Bearpaw Formation southwest of Lethbridge was determined by Yarwood (1931) to be 690 feet and that of the overlying Fox Hills Formation to be 135 feet thick.

Warren (1931) illustrated the megafauna of the Bearpaw Formation and indicated their long vertical range representing most of Cretaceous Montana time. The fauna of the Fox Hills Formation contained Bearpaw marine forms as well as brackish-water forms.

Wickenden (1932) published the first microfaunal data from the Bearpaw Formation in southern Alberta, but no stratigraphic correlation was attempted.

The Bearpaw Formation of Saskatchewan was correlated with its counterpart in Alberta on the basis of its stratigraphic position and faunal content by Fraser *et al.* (1935).

Russell and Landes (1940) studied the relative changes of land and sea during Late Cretaceous time in southern Alberta. They proposed the term "Blood Reserve Formation" for the sandstone bed at the top of the Bearpaw Formation, to replace the term "Fox Hills".

Furnival (1946) revised the interpretation of the Bearpaw Formation and ascribed to it all the marine, dark grey, Pierre shales below the "Brown Sandstone Member" of the Fox Hills in eastern Montana, and above the Judith River Formation. Furnival introduced the names "Thelma", "Belanger" and "Oxarart" for the three successively older sandstone members of the Bearpaw Formation in southwest Saskatchewan. These sandstones were determined to be 30 to 50 feet thick at the Alberta-Saskatchewan boundary and to pinch out about 40 miles east of the boundary.

This terminology was applied by Lines (1947) to outcrops along the western slopes of the Cypress Hills in Alberta, where he established two new members. The term "Manyberries" was used to differentiate the non-sandy lower portion of the Bearpaw Formation from the upper sandier portion. The term "Medicine Lodge" was applied to the dark grey shales above the Thelma Member and below the top of the formation.

On the basis of bentonite correlations between Cypress Hills and the Lethbridge area, Lines suggested that the Bearpaw Sea transgressed rapidly and that the top of the Oldman or Belly River Formation is practically isochronous. He also recognized that the Bearpaw Formation thins slightly in the Lethbridge area and suggested that the Oxarart Sandstone of the east is equivalent to the Blood Reserve Formation of the western region.

Lines (1963) stated that the formation is more arenaceous to the north where he studied a composite section from the Castor area, suggesting that the Formation passes into non-marine beds near the shoreline. He proposed a two-fold division of the Bearpaw Formation for this section, and considered the two members to be equivalent to the lower half of the Manyberries Member in the south. The two members are the Paintearth above and the Young Creek below, separated by a chert pebble bed. The chert pebble bed was suggested as the equivalent of the basal Edmonton conglomerate of the north-central Foothills area, assuming the diachroneity of the upper boundary of the Bearpaw Formation.

Russell's (1950) correlation of the upper part of the Bearpaw Formation between Alberta and southwestern Saskatchewan differed in detail from Furnival (1946). Russell recognized three distinct sandstone members in the upper part of the Bearpaw Formation in southeastern Alberta. He found that the lower sandstone was equivalent to a sandstone which occur 40 feet below the true Oxarart of southwestern Saskatchewan and proposed the name Black Eagle for that sandstone. He correlated the middle sandstone of southeastern Alberta with the Oxarart and Belanger sandstones of southwestern Saskatchewan, and agreed with Furnival on the correlation of the Thelma member of southwestern Saskatchewan with the upper sandstone of southeastern Alberta.

The time interval represented by the Bearpaw Formation would become less and less towards the north and west as suggested by Russell (1950). However, he stated that the base of the formation seemed to be nearly the same age everywhere, thus indicating a rapid transgression and a step by step regression of the Bearpaw Sea.

Loranger and Gleddie (1953) divided the Bearpaw Formation into six zones on the basis of microfaunal content; five of these contain abundant microfauna, based on a study of foraminifera recovered from core samples in southwestern Saskatchewan. The formation is 1030 feet (313.94 meters) thick in that area and they indicate that three of the zones are present in the Lethbridge area but in a more brackish environment. The Blood Reserve Formation was reduced to member status by these authors and they substantiated the conclusions of Russell (1950) that the top of the Bearpaw Formation is approximately 200 feet above the top of the Oxarart Sandstone and that the section above the Oxarart in the plains area is equivalent to the basal part of the St. Mary River Formation in the foothills belt area.

Williams and Burk (1964) noted variations in thickness of the Bearpaw Formation to the west and northwest of the southern plains, such that the formation is probably not present north of the Bow River in the west, and that it grades into the basal Edmonton Formation about 50 miles northwest of the city of Edmonton in Alberta.

Caldwell and North (1964) and North and Caldwell (1970, 1975) established five microfaunal zones for the Bearpaw Formation in southwestern Saskatchewan. On the basis of foraminiferal distribution, they correlated the Bearpaw in the south Saskatchewan River valley with that of the Cypress Hills and Frenchman River valley. These authors noted that the youngest fauna found in the Oxarart and Medicine Lodge Members extends only into the basal beds of the Eastend Formation, and above these beds foraminifers disappear.

> "Such a distribution supports the view, expressed by others, that the Eastend Formation records the transition from marine to non-marine conditions denoting retreat of the Bearpaw Sea from

> southwestern Saskatchewan and the establishment of the continental conditions that were to prevail until the end of Cretaceous time." (North and Caldwell, 1975, p.324).

Many authors contributed to the age determination of the Bearpaw Formation; Folinsbee *et al*.: (1960, 1961, 1965, 1970) by potassium argon methods; Jeletzky (1968) by *Baculites* zonation that was earlier introduced by Landes (1940), and adopted by Cobban and Reeside (1952) for the western interior of the United States.

Shepheard and Hills (1970) described and interpreted, from a detailed sedimentological analysis, the conditions of deposition in the transition zone between the Bearpaw and Horseshoe Canyon Formations (the Horseshoe Canyon Formation is the lower part of the Edmonton Group). Data for their study were derived from 32 stratigraphic sections described approximately ten miles southeast of Drumheller.

Mello (1969) used foraminiferal studies to infer the paleoecology of the upper part of the Pierre Shale in north central South Dakota. North and Caldwell (1970, 1975) interpreted the paleogeography from similar studies in Saskatchewan and Given (1969) and Given and Wall (1971) used foraminifers to correlate the Bearpaw Formation between areas of southeastern Alberta.

Microfaunal studies of the Bearpaw Formation are documented in several unpublished theses. Given (1969) illustrated the foraminifera of the Bearpaw Formation in central southeastern Alberta, Rosene (1972) studied the microfauna in the Lundbreck area in southwestern Alberta, Anan-York (1969) made similar studies in the Lethbridge area, and Harland (1970) studied the dinoflagellates and acritarchs of the Bearpaw Formation in southern Alberta.

Related recent studies are to be found in Caldwell (1975) where several authors dealt with the paleogeography of the Bearpaw Formation and its depositional environment. The following contributions in Caldwell (1975) are noteworthy. Williams and Stelck (1975) illustrated the paleogeography of the Late Cretaceous seas. Reiskind (1975) interpreted the paleoecology from a study of fossiliferous concretions from the Bearpaw Formation of eastern Montana and southwestern Saskatchewan. Wall (1975) correlated the lower part of the Bearpaw Formation in southern Alberta on the basis of diatoms, confirming that the basal beds of the formation are younger in central Alberta than in the south of the province and that the contact of the Bearpaw and underlying Judith River Formation (formerly Belly River) rises diachronously to the north. This agrees with a similar conclusion (Caldwell, 1968) established by the disappearance of ammonite zones progressively westwards from the Saskatchewan River valley to the Cypress Hills.

Wall (1975) suggested from the increase in the degree of pyritization of diatoms and radiolarian tests to the west of the Cypress Hills area, that there was a shallowing of the sea to the west with the waters becoming stagnant, probably due to restricted circulation in local depressions on the sea floor.

A study by Given and Wall (1971) in the Castor area of Alberta is of direct relation to the present work as a complete core of the Bearpaw Formation is described and related to an electric log of the borehole. The geophysical log response provided a link between this work and their findings in the Castor area which lies at the northeastern corner of the study area.

B. Description of the Bearpaw Formation

The Bearpaw Formation consists of dark clays with numerous fossiliferous calcareous concretions in its type locality on the slopes of the Bearpaw Mountains in Montana (Stanton and Hatcher, 1905). There the dark clays directly overlie non-marine deposits of the Judith River Formation and attain a thickness of several hundred feet. They are identical in their fauna and lithologic features to part of the Pierre Formation of South Dakota. In western Canada, the Bearpaw Formation ranges in age from late Campanian to early Maestrichtian time (Jeletzky, 1968), represented by most of the *Baculites compressus* Zone of Landes (Landes, 1940; Cobban and Reeside, 1952) in the Plains and Foothills regions of western North America. A potassium-argon age determination on a bentonite (Folinsbee *et al*., 1960, 1961) 65 feet above the base of the Bearpaw Formation gave a date of 75 ± 4 million years.

The Bearpaw Sea is known to have extended as far north as the Edmonton area (Feniak, 1944), but the northern and eastern limits of the sea in Saskatchewan and Manitoba are unknown as the present distribution of the formation is controlled by post-Bearpaw erosion. Several occurrences of supposedly Late Campanian shales in the Northwest Territories in the area between Great Bear Lake and the Richardson Mountains suggest that the Bearpaw Sea may have extended to the Arctic through northern Saskatchewan (Martin, 1961).

In Alberta, outcrops of the Bearpaw Formation may be divided into three main belts, namely the western belt, the central outcrop belt and the eastern outcrop belt (Russell, 1950), the latter of which extends into southern and southwestern Saskatchewan.

The western belt is within the Foothills of the Rocky Mountains, and being on the western limb of the Alberta syncline, the strata dip strongly eastward. In this region the formation thickness is difficult to determine due to faulting and folding. The formation is probably no longer present north of the Bow River in the west (Williams and Burk, 1964).

The central outcrop belt extends from the Foothills to the Sweetgrass Arch and from the United States border to about 50 miles northwest of Edmonton (Feniak, 1944). The Bearpaw Formation is generally absent from the structurally high Sweetgrass arch where older strata are exposed (Williams and Dyer, 1930; Russell, 1950). The thickness of the formation is about 810 feet in the south (Lines, 1963), and gradually thins to the north and west. East of Calgary, the Bearpaw Formation is about 350 feet thick and it is 100 feet thick or less west of Edmonton (Williams and Burk, 1964).

The eastern outcrop belt of the Bearpaw Formation is in the Cypress Hills where the formation attains a thickness of about 1030 feet (Loranger and Gleddie, 1953). This outcrop belt extends into southwestern Saskatchewan where it forms the bedrock surface over the greater part of the area (Caldwell, 1968).

According to Lines (1963), the lower contact of the Bearpaw Formation with the underlying non-marine Oldman or Judith River Formation is sharp and apparently conformable, representing a rapid transgression of the sea. The contact is placed at the top of the uppermost coal-bearing and carbonaceous shale beds of the Belly River Formation (Ower, 1960).

The upper contact of the Bearpaw formation with the non-marine Edmonton, St. Mary River, or Eastend Formation is gradational and diachronous. The sandstones of these formations replace the shales of the Bearpaw vertically in the section as well as laterally to the north and west (Williams and Burk, 1964).

The Bearpaw shales are marine and generally dark grey, weathering to brownish-grey; silty shales are usually brownish-grey. Fresh shales may be blocky or laminar, and selenite crystals and iron oxide staining are frequently present on outcrop surfaces (Given, 1969).

The sandstone beds of the Bearpaw Formation are medium to fine grained and often glauconitic. Numerous sandy lenses are present locally but are not believed to be continuous over any great distance.

Clay ironstone concretions are present within the Bearpaw Formation, are often fossiliferous and may provide local marker beds. Bentonite beds are common in the formation, ranging from a fraction of an inch thick to as much as 8 inches thick in the Lethbridge area and are also useful local markers. Coal beds ranging from one foot thick to as much as four feet thick are present especially within the sandy intervals of the Bearpaw Formation, and provide excellent local markers (Link and Childerhose, 1931).

III. STRATIGRAPHIC ANALYSIS

A. Introduction

This chapter is concerned with the subsurface distribution, geometry, and vertical and lateral variation of the Bearpaw Formation in southcentral Alberta as determined in this study. The formation is exposed along the eastern limit of the study, within the northern part of the central outcrop belt of Russell (1950).

A study of a complete core of the Bearpaw Formation at Castor and surface exposures on the Bow and Red Deer Rivers (Given, 1969; Given and Wall, 1971) provided means for relating subsurface investigations to studies made on outcrops and core descriptions.

B. Limitations

The present study was based entirely on data from electric and radiation logs from petroleum exploration boreholes. Data obtained from these logs is subject to several limitations. The shape and magnitude of deflections of the log curves are basically a record of the variation or contrast in electrical or radiation response of the strata logged. However, additional factors such as variable sizes of boreholes (caving, etc.) and different types of drilling fluids influence the response of the logging device. The resultant shape of the curve is a reflection of the lithological variation as well as the influence of these factors from well to well, thus curves for a similar stratigraphic section may be different quantitatively but comparable qualitatively. Additional variability stems from the fact that the the logs used in this analysis were produced by various logging companies with their patent logging techniques, in some instances using different scales for recording the parameters being logged. A third limiting factor is the variably reduced response of the spontaneous potential curve in sandstones within shaly formations such as the formation under study.

In addition to these three main limitations, the subjective personal error in the process of lithological interpretation of both types of logs by a worker must be considered.

Marker horizons and contacts for the various subsurface stratigraphic units have been qualitatively determined by the curve characteristics of the logs. No attempt was made to examine the influence of various disturbing factors on the quantitative interpretation of the log curves for the purpose of this study. Sandstones and shales and their transitions are the only lithologies involved in this study; generally the sandy zones are intercalated with silty and shaly material, and thus the boundaries between the units tend to be gradational. In particular the lower boundary of the Bearpaw Formation was difficult to determine as the upper part of the Judith River Formation consists of green shales and carbonaceous shales that produce similar responses on geophysical logs to the shales of the Bearpaw Formation.

C. Bearpaw Formation Contacts

The Bearpaw Formation is defined by Allan and Sanderson (1945) as the dark, argillaceous, marine beds which overlie the Belly River (Judith River) Formation. They believed that the lower contact is everywhere sharply defined, but that the upper contact with the Edmonton Formation is gradational and indistinct. In southern Alberta the lower contact of the Bearpaw Formation is placed at the top of the Lethbridge coaly and carbonaceous member of the Judith River Formation. The Lethbridge member is not clearly represented in the area of study and adjacent localities, and the contact was placed at the top of the uppermost sandstone of the Judith River Formation by Ower (1960), and at the top of carbonaceous beds of that formation by Given and Wall (1971). Elliot (1960) lowered the base of the Bearpaw by 200 feet from that of Ower (1960) according to petroleum borehole data on the uppermost sand in the Judith River Formation.

In east central Alberta the top of the Bearpaw Formation becomes transitional according to Shaw and Harding (1949), and progressively grades into the overlying continental beds of the Horseshoe Canyon Formation to the northwest. The Bearpaw Formation of the south Saskatchewan River valley contains sand members that are widely distributed and valuable as markers. Caldwell (1968).

demonstrated that some of the lower sands within the Bearpaw are continuous with sands of the Judith River Formation, and that a similar relationship is probably present for the upper sands of the Bearpaw Formation and their continental counterparts in the Horseshoe Canyon Formation.

In agreement with Caldwell's interpretation, the distribution and variation of units in the Bearpaw Formation in the area of study indicate that the upper and lower contacts of the formation are transitional. Sandstones are widespread and continuous, but the position of the change from brackish-fresh water sandstones to marine sandstones of the Bearpaw could not be determined as the study was limited to subsurface correlations based on geophysical logs.

The lower contact of the Bearpaw Formation is placed at the top of the uppermost fining-upward sequence of the Judith River Formation. The top of the fining-upward sequence is placed at the uppermost sandstone bed in the sequence, and the shale unit overlying the sandstone is considered the basal bed of the Bearpaw Formation.

The contact between the Bearpaw Formation and the overlying Horseshoe Canyon Formation is placed at the top of the uppermost shale unit of the Bearpaw Formation and at the base of the lowermost continental sandstone of the Horseshoe Canyon Formation.

D. Log Signature

Typically, the log signature for the top of the Judith River Formation is a gradational right deflection towards the shale line of the spontaneous potential curve, (figure 4), generally less than five millivolts, combined with a deflection to the left (a decrease) of the resistivity curve. Similar responses are noted on radiation and density logs that occasionally accompany electric logs, but to maintain consistency only electric logs are presented and tabulated in this study.

Similarly the base of the Horseshoe Canyon Formation is taken at the base of the first significant indication of consistent continuous sandstone (negative spontaneous potential, positive resistivity) above the Bearpaw Shales which are replaced by sandstones of the basal Horseshoe Canyon Formation.

E. Subsurface Correlation

Almost all the Bearpaw succession of the study area is represented in the Research Council of Alberta Castor Well studied by Given and Wall (1971) (Lsd. 13, Sec. 34, Twp. 37, Rge. 13, W. 4 Mer). Their terminology (figure 5) has been used where appropriate due to the proximity of their study and the consistency of log signatures.

Six coarsening-upward cycles are recognized in the Bearpaw succession of the study area. The five lower units are named A to E, the lower part of the uppermost cycle is

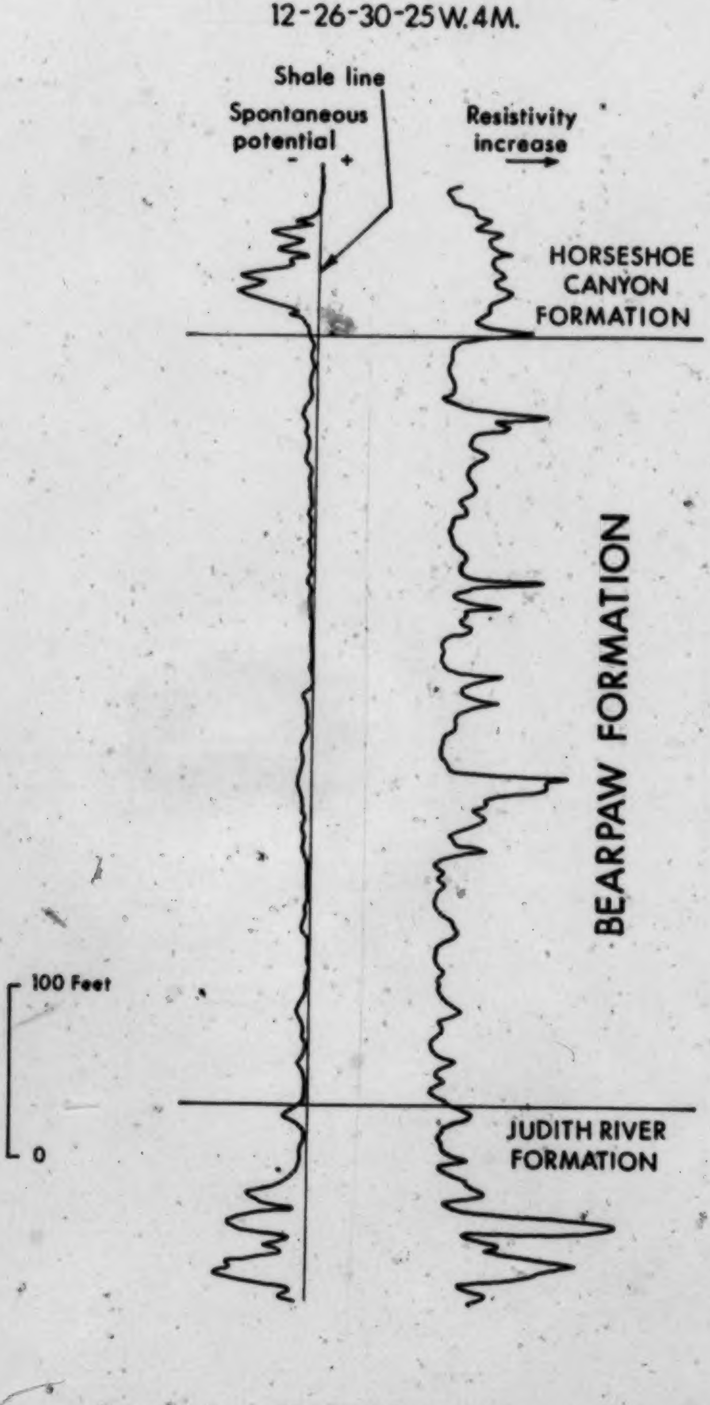


Figure 4. Electric log signature of the Bearpaw and adjacent Formations, Southcentral Alberta.

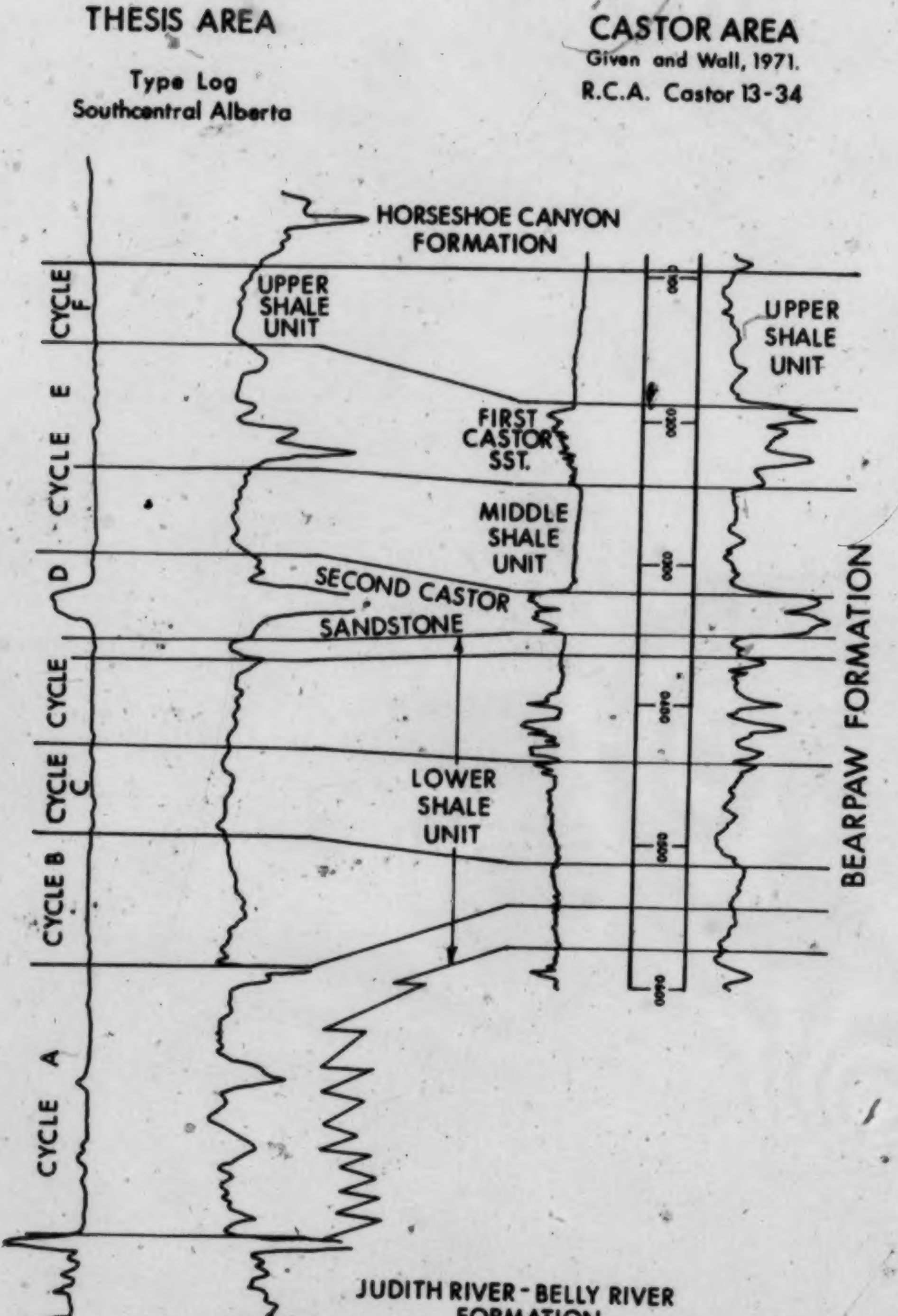

THESIS AREA
Type Log
Southcentral Alberta
CASTOR AREA
Given and Wall, 1971.
R.C.A. Castor 13-34
HORSESHOE CANYON FORMATION
CYCLE F
UPPER SHALE UNIT
CYCLE E
FIRST CASTOR SST.
MIDDLE SHALE UNIT
CYCLE D
SECOND CASTOR SANDSTONE
CYCLE
CYCLE C
LOWER SHALE UNIT
CYCLE B
CYCLE A
UPPER SHALE UNIT
BEARPAW FORMATION
JUDITH RIVER - BELLY RIVER FORMATION

Figure 5. Correlation of the Bearpaw Formation between Castor and the area of study.

referred to the Upper Shale Unit of Given (1969) and Given and Wall (1971), and the coarse fraction of the uppermost cycle is considered the basal unit of the overlying Horseshoe Canyon Formation. Cycle A is apparently not represented in the Castor well. The Lower Shale Unit of Given and Wall (1971) is equivalent to beds in cycle B to the base of the coarse fraction of cycle D. The Second Castor Sandstone (Given and Wall, 1971) is equivalent to the coarse fraction of cycle D which is widely distributed in the area. To the west, this sand increases in thickness and replaces the clays and silts of the underlying finer portion of cycle D. The Middle Shale Unit and the overlying First Castor Sandstone are equivalent to cycle E and respectively represent the fine and coarse fractions of the cycle. Cycle E shows the same relationship that is represented by the underlying cycle D, *viz.* the sands replace the shales and silts of the lower part of the cycle until the Middle Shale Unit wedges out to the west. In addition the Upper Shale Unit of the Bearpaw Formation is replaced by the overlying Horseshoe Canyon Sands (coarse fraction of cycle F) to the west along the section, (figure 6), and most probably to the north of the study as mentioned by other workers (Russell, 1950). Tongues of sand, that could be traced in the subsurface to the north and northwest appear occasionally within the Upper Shale Unit, and these relationships merit further investigation. The lower sands of the Horseshoe Canyon Formation climb stratigraphically to the east and southeast as demonstrated by thickening of the Upper Shale Unit in those directions which is in agreement with previous studies (Caldwell, 1968).

Six stratigraphic cross sections were constructed within the study (illustrated by figure 2) based on detailed electric log analysis of the Bearpaw Formation. The sections establish correlation to a type locality described by Given and Wall (1971), illustrate the distribution and geometry of the Bearpaw sediments and describe the vertical and lateral changes in the lithology in the formation.

Three cross sections (figures 6, 7, and 8) run east to west in Townships 36 (figure 6), 30 (figure 7), and 25 (figure 8) in a direction normal to regional strike.

Three north-south sections along Range 2 W 5 (figure 9), Range 22 W 4 (figure 10) and Range 19 W 4 (figure 11) complete the grid of cross sections which illustrate the progressive thinning of the Bearpaw Formation to the west, north and northwest by the transitional change of the Upper Shale Unit and the Middle Shale Unit into sands of the overlying Horseshoe Canyon and the First Castor Sandstones, respectively.

IV. DEPOSITIONAL CYCLES

> "... during the Late Cretaceous Epoch, ... movements of land and sea are recorded in the sedimentary sequence, which broadly, between the Rocky Mountain foothills of Alberta and the plains of eastern Saskatchewan and Manitoba, is cyclic and composed of marine, brackish-water, and fresh-water clays, silts, and sands" (Caldwell, 1968, p.1).

If the strand line remains stable for a sufficient period of geologic time and environmental conditions permit, the formation of lignite and coal may occur.

The Bearpaw Formation as encountered in the subsurface of the study area, consists of six depositional cycles of coarsening-upward sequences of clastics that range from clay to sand size. Coal seams tend to occur mainly above sandy to silty beds near the top of a cycle. Only the fine phase of the uppermost cycle was considered, as the coarse fraction was considered to be the basal unit of the overlying Horseshoe Canyon Formation, and the unit is referred to as the Upper Shale Unit. The other five cycles in ascending order are referred to as cycles A, B, C, D, and E (figure 12).

Cycle A

The lower part of this cycle is mainly shale and silty shale with sand lenses in the middle part of the interval. This part of the Bearpaw Formation is transitional from the underlying Judith River Formation, and sand lenses probably grade laterally into the underlying formation. Figure 13 illustrates the thickness distribution of this unit and

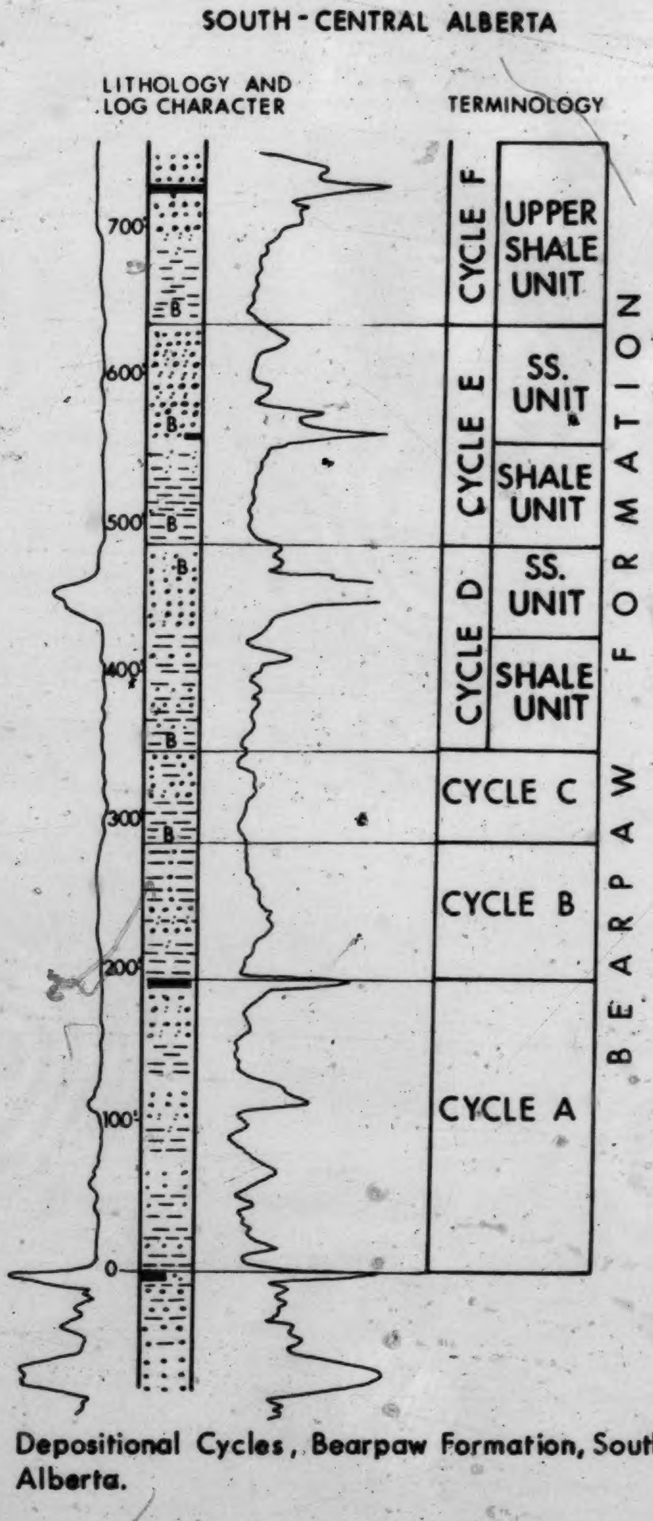

SOUTH-CENTRAL ALBERTA
LITHOLOGY AND LOG CHARACTER
TERMINOLOGY
700'
600'
500'
400'
300'
200'
100'
0
B
B
B
B
B
B
CYCLE F
UPPER SHALE UNIT
CYCLE E
SS. UNIT
SHALE UNIT
CYCLE D
SS. UNIT
SHALE UNIT
CYCLE C
CYCLE B
CYCLE A
BEARPAW FORMATION

Figure 12. Depositional Cycles, Bearpaw Formation, South Central Alberta.

indicates its widespread distribution. It is somewhat irregular in distribution and thickens to a maximum of 200 feet along the central part of the area, with thicker areas trending in a north to northeast direction indicating the center of deposition. The unit thins to the northwest to about 100 feet and to the southwest where the thickness is 70 feet. A similar trend is encountered in the northeast and southeast respectively, with the variation possibly explained by irregularities in the basin of deposition inherent from the Judith River surface on which the sediments of this basal unit of the Bearpaw Formation were deposited. The distribution of the lower unit in the western part of the area is probably explained by facies change relationships with the underlying Judith River sands. Areas where the lower part of the cycle is thin probably represent areas closer to the Judith River delta front whereas thicker sections represent areas farther from the delta front and deeper into the sea.

It is difficult to explain the thinning of this lower unit to the east and southeast in the study area in terms of a transgression apprpaching from the southeast as inferred for the advance of the Bearpaw Sea. The only explanation that would probably fit the thickness distribution in that part of the area, is the presence of highs in areas of lessened thickness or perhaps the basin of deposition was shallower in these localities. Williams and Burk (1964) showed two sources for clastics of the underlying Judith

River Formation, one from the southwest and one from the northwest, and Stelck (1975, p.438) referred to the effect of the Sweetgrass arch in deflecting the sediments "... somewhat to the lows on either side ..." of the arch; and, "... it retained the coarser clastics within the old Precambrian basinal areas." It follows that during the deposition of the lower unit of cycle A the Sweetgrass arch probably affected its thickness distribution, as much as the local irregularities on the Judith River.

The upper part of this cycle grades from the lower shaly unit and forms the first coarsening-upward sequence in the Bearpaw Formation. It consists of siltstone that grades into a sandstone towards the top, commonly with interfingering between shaly sands and silty shales. Coal is present within the sandy zone and can be traced for considerable distances within the area. The top of the sand represents a sharp contact with the overlying unit and is used as the datum for the cross sections because of its wide distribution in the area. The lower contact of the sandy zone tends to be gradational with the underlying shaly part of the cycle and is difficult to determine an exact boundary.

The distribution of the sandy, upper part of cycle A is illustrated by figure 14. The sand is thickest in the west, where more than 140 feet are encountered, and thins to the east where it is less than 10 feet thick. Four major east-west trending thick areas with intervening thin areas are apparent on the map (figure 14). The area of thick sediments in the north thins to the southeast in the form of lobes separated by thin areas that trend northwest - southeast. The remaining areas of thick sediments in the central and southern part occur in the form of radial patterns originating from the west. Thicker sand distribution takes the form of elongate lobes that are separated by areas where the thickness is less than 20 feet (figure 14). The linearity of features in figure 14 could be potentially caused by three factors. The first factor is probably the selection of control points along east-west lines and no attempt could be made to investigate this possibility due to the poor quality of borehole electric logs between the control points used in the study. The other two factors are depositional processes and tectonic influences and these will be discussed in forthcoming chapters.

The following observations follow from the distribution of cycle A on the stratigraphic cross sections and isolith maps (figures 6 to 11, 13 and 14):

1. Cycle A represents a coarsening-upward sequence of deposition. Clay (or shale) grades up into interbedded clay and silt or very fine sand.
2. Sheet and channel sands probably form the coarse fraction of the cycle and are widespread over the area.
3. The total thickness of the cycle varies from 100 to 240 feet.

4. Coal is present above sands in a number of wells and individual beds can be traced for several miles.

Moreover, the sandy zone of cycle A is very thick in the west along the trends seen in figure 14. From the south, the first trend is thickest (132 feet) in Lsd: 10, Sec. 24, Twp. 25, Rge. 2, W. 5 Mer., and spreads to the east in four thick lobes, only one of which continues for any distance to the east, maintaining a thickness of 100 feet in the center of the trend. A thickness of 97 feet is encountered farther east in Lsd. 6, Sec. 1, Twp. 27, Rge. 15, W. 4 Mer., which indicates the continuity of thick distribution after which the sand becomes progressively thinner to the north, northeast, and southeast.

North of this trend, another body of similar thickness abruptly thins to the east in the vicinity of Rge. 1, W. 5 Mer., where its distribution is overtaken by a third lobe coming from the northwestern part of the area. This latter lobe, more than 140 feet thick, extends from the northwest towards the south and southeast in two trends that continue to the east.

Only part of the most northern distribution is included in the study area. The interval is thicker in the north and northwest and thins to the south and east. It appears that the sandy zone is more northerly oriented than its counterparts in the central and southern parts of the map area. However, there is little doubt that both sands are equivalent, although a more northerly source area might be suggested for the interval in the north.

Facies change explains the variation in thickness of the sandy zone as it replaces the clays and silts in a westerly direction so that the lower unit of this cycle is relatively thin in the west below the thick trends of the sandy part of the cycle.

Only the top 34 feet of this cycle are included in the basal beds of the "Lower Shale Unit" of Given and Wall (1971) in the Castor well, which accounts for the sandy zone and part of clays and silts beneath the sand in the cycle. The interval as described from core by Wall (1971), consists of 28 feet of medium to dark grey shales interbedded in the lower 14 feet with occasional silt laminae, plant remains and few bentonite layers in the middle of the core. The upper 14 feet of the core contains similar shales, but differ from the lower interval by the appearance of prominent lenses and stringers of silt and sand in the upper seven-foot interval.

Cycle B

This unit also forms a coarsening-upwards sequence yet spans a smaller interval than the underlying cycle and probably represents a sequence that was interrupted at the time of deposition. The lower contact of cycle B is well defined in most well logs by a sharp decrease of resistivity (deflection to the left), and a noticeable increase of spontaneous potential (deflection to the right), seen in figures 6 to 12. The upper contact is difficult to determine due to the abrupt changes in facies of the top part laterally across the area.

The unit consists of a lower shale and an upper silty interval interbedded with silty sandstone at the top. It is well defined and traceable in the southeastern part of the area and particularly along section CC′ (figure 8). The thickness of the unit is 110 feet in Lsd. 10, Sec. 9, Twp. 25, Rge. 19, W. 4 Mer., and it can be divided in ascending order into a lower 40 foot shale, a middle 60 foot siltstone and a 10 foot silty sandstone. Along section DD′ the upper contact of this cycle is placed at the top of the silty sandstone interval, which is overlain by the basal shales of cycle C. The fine fraction of this unit, represented by the shales at the base, progressively thins to the west in Lsd. 6, Sec. 11, Twp. 25, Rge. 3, W. 5 Mer., where it is approximately 25 feet thick and is underlain by a sandy bed that probably originated from the west as a shoreline facies, perhaps extending from the underlying sandy zone of cycle A.

The shale also decreases in thickness to the north (figure 7) where it is approximately 30 feet thick in the eastern part of the section, and is interbedded with silt in the western part of the section. The shale is not well defined further north along section AA′ (figure 6) especially in the Castor well, and the adjacent well to the west where the apparent thickness of the shale is about 15′

feet or less. Silt replaces the shale to the west along section AA′ and the shale is not more than a few feet thick in the far west of the section.

The overlying silty interval thins gradually from the east along section CC′ and becomes sandy from Lsd. 11, Sec. 20, Twp. 25, Rge. 22, W. 4 Mer. to Lsd. 6, Sec. 11, Twp. 25, Rge. 3, W. 5 Mer. Similar conditions occur along section DD′ to the north where the interval loses its characteristic appearance on the logs in Lsd. 11, Sec. 18, Twp. 30, Rge. 21, W. 4 Mer. and is replaced by sand from that position to the western part of the section. Farther to the north, along section AA′, the silty interval becomes sandy and difficult to correlate with the rest of the area and is included in the silty sandstone and sands of the overlying part of the cycle.

The uppermost part of cycle B is a silty sandstone which was rather difficult to correlate across the area as it is relatively thin. It defines the contact between this cycle of deposition and the overlying shale. It is mainly apparent along section CC′ where it thickens to the west to a maximum of 40 feet, largely replacing the underlying silty interval. This replacement is also seen along section BB′ (figure 7) in Lsd. 12, Sec. 26, Twp. 30, Rge. 25, W. 4 Mer., where a noticeable coarsening-upward unit is more apparent and where a coal seam overlies the sandy interval. A similar situation exists along section AA′ (figure 6) where the silty sand is overlain by a silty interval with a 3 foot coal seam at the top. The coal is apparently not present east of Rge. 22 W. 4 Mer. in section AA', east of Rge. 23 W. 4 Mer, on section BB' and along section CC'. The sandy interval is difficult to trace to the northeastern corner of the area and only the top of the underlying silt can be seen on section AA'.

Cycle B is represented in the Castor well by a 35 foot interval of shale which contains lenses of silt and fine-grained sand in the lower half and thin sandy intervals in the upper half. The sandy shale intervals described are not greater than one foot thick and are most probably a continuation of their counterparts described in cycle C.

East of Rge. 22, W. 4 Mer. the top sandy and silty interval of cycle B changes to silty shales and shales. The cycle become fining-upwards in grainsize as illustrated by the type log (figure 5) and the stratigraphic sections, and this represents a facies change of the top of cycle B to the east in the area of study.

Cycle C

This cycle forms the third coarsening-upward sequence in the Bearpaw Formation and is similar to the underlying unit in thickness. It consists of a lower shale interval; which is overlain by a silty and sandy interval which is in turn overlain by a coal seam at the top. The unit is best illustrated in the western part of the area along sections AA', BB', and CC'. The log signature is well represented in Lsd. 11, Sec. 20, Twp. 25, Rge. 22, W. 4 Mer. on section CC' where the unit is 67 feet thick. To the east, the coal seam is replaced by a sandy bed that continues to the eastern part of the section with a slight carbonaceous content as reflected by dfferences in the shallow and deep resistivity curves. The silty nature of the shale decreases slightly to the east also. West of Twp. 25, Rge. 22, W. 4 Mer. on section CC′ the shale becomes progressively more silty with prominent sandy interbeds..Although this cycle is much thinner than cycle A, it reflects a similar lithologic character as portrayed by the log signature.

Individual components of this unit have similar distribution to the components of cycles B and A along section AA′ and, the pinching out of the coal takes place at almost the same locality as the coal seam of cycle B (east of Rge. 22, W. 4 Mer.). This change occurs slightly farther west along section BB′ (east of Rge. 25, W. 4 Mer.).

Correlation of this interval with the Castor well is shown by section AA′ where this interval is equivalent to beds from 90 to 160 feet above the base of the Bearpaw Formation in that well. There the shales are more silty and sandy grading into the upper part of the unit with an increase in sandy interbeds. The sands are greenish, glauconitic, fine grained, generally bentonitic and occasionally contain shell fragments. A sandstone, fine to medium grained, non-calcareous, with kaolinitic cement was described 7 feet below the top by Given and Wall (1971).

Cycle D

This succession is easily recognized by a general coarsening-upward in grain size distribution in Lsd. 10, Sec. 9, Twp. 26, Rge. 17, W. 4 Mer. along section CC′ and represents an important part of the Bearpaw Formation. The lower two thirds of cycle D is equivalent, in the northeastern part of the area, to the upper part of the 'Lower Shale Unit' of Given and Wall (1971), and the upper one third of the cycle is equivalent to their "Second Castor Sandstone" member.

In the southeastern part of the study, the lower two thirds of this cycle consist mainly of 50 feet of bentonitic shales, and silty shales that grade upwards into 40 feet of interbedded sandstones and silty sandstones in the middle part. The middle succession grades upwards into a shaly interval approximately 40 feet thick below the base of the overlying Second Castor sandstone equivalent which constitutes the upper third of the cycle.

Further subdivision of this cycle to the northwest and west of this locality (Twp. 26, Rge. 17, W. 4 Mer.) is necessary as the one cycle character is no longer apparent. A two cycle division of this unit can be seen in that part of the area along all cross sections. The lower cycle, also a characteristic coarsening-upward sequence, consists of bentonitic shales at the base that grade upward into silty shales, and finally towards the top sandy beds appear and are overlain by a coal seam that attains a thickness of 4 feet. The upper cycle consists of the 40-foot shaly interval and the overlying second Castor sandstone that formed the upper part of the cycle in the east.

Lower Sub Cycle: The upper part of this cycle is characterized by the presence of a coal seam at the top of the succession, and is similar in distribution to cycles B, and C. The lower silty shales of this unit change laterally to the west into silty sands and sandstone with thin beds of clays. Shales thin to the west and are completely replaced by silt and sand interbeds (figure 7), that continue upwards to replace the remaining part of the lithology in the cycle. Thus the coal seam distribution is limited between Rge. 22, W. 4 Mer. and Rge. 19, W. 4 Mer. in figure 6, and extends farther west in figure 7, and is limited between Rge. 25, W. 4 Mer. and Rge. 20, W. 4 Mer. in figure 8.

The Upper Sub Cycle: The unit consist of a lower shale interval and an upper sandy interval that consists of silty sands and sands that are equivalent to the Second Castor Sandstone of Given and Wall (1971). The cycle is widely distributed over the area and averages 100 feet in thickness. As the underlying coal seam is not recognizable west of Rge. 25, W. 4 Mer. (figure 8), both the lower and upper cycles merge to form one cycle as the intervening shale of the upper cycle thins to the west.

The upper part of this cycle is a prominent sandstone that has been described in the northeastern part of the study by Given and Wall (1971). The sandstone is 34 feet thick and is greyish-green in color. It is medium-grained, glauconitic and has a non-calcareous kaolinitic cement. The lower part of the sandstone is slightly argillaceous and contains bentonitic laminae. The upper part of the sandstone is cleaner and has a fair porosity as reflected by the log signatures (figures 6 to 11).

The log signature of the sandstone in the area of study reflects the presence of clay, as the resistivity decreases within the interval and the spontaneous potential increases towards the shale line. The fair porosity zone indicated in the Castor area is not as simple to correlate, but can be indicated in those wells where the spontaneous potential deflection is considerably more negative than it is for the lower argillaceous part of the sandstone.

From the different cross sections (figures 6 to 11), the Second Castor Sandstone equivalent is illustrated to spread widely over the area, with minor variations. Along section AA′ the sandstone is continuous to the west and thickens to more than 70 feet as the lower cycle is replaced by sands, and is more than 100 feet thick farther to the west. The upper limit of the sand is difficult to interpret as the overlying shale of cycle E is not present west of Range 25 west of the Fourth Meridian along this section. A similar condition prevails along sections BB′ and CC′ where the upper boundary of the sandstone is not clear west of Range 1 and 2 west of the Fifth Meridian.

The distribution of the Second Castor Sandstone equivalent is illustrated in figure 15. From south to north, five major thickness accumulations (enclosed by the 100-foot isolith) can be seen. Thickness concentrations are elongate lobal features radiating from the west. Each accumulation has its own network of lobate extensions radiating from the main sand body. All the accummulations have a central thick distributional trend that thins to the north, south and east of the main body. Only four of the main sand bodies continue across the area to the east. The maximum thickness attained is 158 feet in the west (Lsd. 10, Sec. 22, Twp. 26, Rge. 1, W. 5 Mer.). The maximum width of the lobate distributions is approximately 12 miles.

The systems of thick distribution are separated by areas where the sandy unit is relatively thinner, and transitional into lateral facies. The sandy unit is widely distributed over the area and thins to the east yet is present in all the wells studied and, the 25-foot isolith is inferred in the eastern part of the area.

Cycle E

This unit represents the fifth major coarsening-upward sequence in the Bearpaw Formation and appears to have a paleogeographic significance as will be discussed in later chapters. It is easily identified by a two-fold division into a lower shale unit and an upper sandstone unit. The two units are correlative with the Middle Shale Unit and the First Castor Sandstone of Given and Wall (1971) and are widely distributed in the area of study.

The lower shale unit has an average thickness of 80 to 90 feet in the eastern part of the area and thins gradually to the northern, northwestern and western parts of the area. It is generally bentonitic and silty with lenses of silt throughout most of the interval in almost all the well logs studied. The presence of silt in the lower shale unit is also indicated by Given and Wall (1971) in their core description. The silt fraction is dominant in the basal part of the shale and the thickness of silty interbeds decreases in the middle and increases towards the upper part of the shale. Their description is in close agreement with the interpretation of the log signature of the present study.

The distribution of the shale member of the cycle is also illustrated in figures 6 to 11 and figure 16. In the northern part of the area (figure 6) a gradual decrease in thickness of the shale unit is clearly apparent from the well logs, until finally the shale pinches out to the west of Range 25 West of the Fourth Meridian. Consequently the contact with the overlying First Castor Sandstone is stratigraphically lower in the west than it is in the east as the lower beds of the overlying sandstone replace the shale. The decrease in thickness of the shale is 73 feet from the Castor well to the wells in the west, a distance of approximately 72 miles. A similar situation exists along section BB', but the shale extends farther west to the vicinity of Rge. 1 W. 5. The decrease in thickness is approximately 100 feet in about 84 miles (figure 16). A similar trend is illustrated by section CC′ where the shale unit is less than 30 feet in the extreme western part of the section.

Figure 16 illustrates the distribution of the shale unit of cycle E in the area of study. The shale increases in thickness to the east and southeast in the area. Areas where the shale is thin are elongate and lobate in pattern, and are separated by areas where the shale unit increases in thickness. The zero isolith represents the western limit of distribution of the shale unit, and the 150 foot isolith is tentatively drawn where the unit reaches its maximum thickness in the area of study.

The upper part of cycle E is transitional from the underlying shale unit and consists of a sandstone interval which is equivalent to the First Castor Sandstone of Given and Wall (1971). As described by Given and Wall, the sandstone interval is silty at the base and contains bentonitic shale laminae. The silty beds are overlain by a medium-grained, non-calcareous 39-foot sandstone with bentonitic and rare carbonaceous lenses and laminae. This sandstone interval is calcareous in places and has a kaolinitic cement. It is overlain by a 6-foot medium to coarse-grained sandstone interval which is grey and grey-green in color with bentonitic laminae and occasional carbonaceous lenses. The overlying 7-foot interval is a coarse-grained sandstone which is moderately glauconitic. It contains only few bentonitic laminae and carbonaceous stringers, and has fair porosity. Overlying this unit, the uppermost 5-foot sandstone interval is medium to coarse-grained, strongly glauconitic in the upper foot, with kaolinitic cement, and buff colored clay beds. The upper contact of the First Castor Sandstone is placed at the base of an overlying bentonitic shale.

This sandstone interval was correlated into adjacent wells in the area on the basis of its stratigraphic position and log signature and was found to extend over much of the area. The lower boundary of the sandstone can be traced westerly to the pinchout of the underlying shale unit in the western part of sections AA′ and BB′. West of that position it is difficult to establish the lower boundary and the two sandstones (First and Second Castor) join to form one continuous sandstone interval. The intervening shale unit between the two Castor sandstones extends further west along section CC′ as discussed earlier and thus the lower boundary of the First Castor Sandstone is well established along the southern edge of the study area.

The upper contact of the sandstone is determined by the base of the overlying Upper Shale Unit and the distribution of that unit is limited to the eastern part of the area (discussed in the next section). Thus the top of the sandstone can only be traced (at least by this study) east of the zero isolith of the overlying Upper Shale Unit. West of that position the sandstone merges with the lower sandstones of the overlying Horseshoe Canyon Formation and it is difficult to determine the top of the sandstone in that area. Intervals of the sandstone become extremely carbonaceous to the west of that locality indicating a facies change and transition from the sandy nature of the interval in the east. According to Lines (1963), the sandstone is 30 feet thick northeast of the Castor well, and is described as a bentonitic, white weathering, typical non-marine sandstone. Lines (1963) believed that lithologically the sandstone is similar to higher Horseshoe Canyon sands (Edmonton Group), but included it with the Bearpaw succession.

Along section BB′ (figure 7) the sandstone is considerably thicker in the west than it is in the eastern part of the section especially when its upper limit becomes difficult to interpret, beyond Range 22 west of the Fourth Meridian. A similar distribution of the sandstone is illustrated by section CC′ (figure 8).

Distribution of the First Castor sandstone is illustrated by figure 17. The sand is present in the eastern part of the map area between Range 15 and 23 west of the Fourth Meridian. The sand isoliths trend somewhat similar to the lower shale unit (figure 16), with a different location of thin and thick areas of sandstone distribution.

Six major areas are illustrated by the map, where thicker lobate sandstone bodies extend from the west to the east. These trend to the southeast in the southern part of the map and occupy a position that coincides with areas of thin distribution of the shales underlying the First Castor Sandstone, and a similar comparison, yet in reverse, exists for the areas where the sand is thin. A change to a more easterly trend takes place in the thick sand lobes further north in the central and northern parts of the map area, with radiating distributary lobes and fingers of sands branching from the main sand body. Farther north a more northeasterly trend is recognized.

Upper Shale Unit

This represents the uppermost succession in the Bearpaw Formation and is part of yet another coarsening-upward sequence recognized in the study area. It is underlain by the First Castor Sandstone and overlain by the basal beds of the Horseshoe Canyon Formation. The lower contact is somewhat gradational from the top of the sandstone in places and sharp in others. The upper contact of the unit is also gradational and intertongueing with the overlying basal Horseshoe Canyon beds (figures 6-11). The unit is described in the Castor well (Given and Wall, 1971), where it consists mainly of shale which is medium to dark grey in color. The shale contains bentonitic, silty laminae and disseminated carbonaceous material at different intervals of the core. A similar distribution of lithologies is correlated from the well logs of the area of study. Furthermore the shale unit contains sandy tongues that can be shown to pinch out to the east (figures 8 and 11).

As illustrated by the stratigraphic cross sections, the shale unit pinches out to the west between Lsd. 1, Sec. 32, Twp. 36, Rge. 20, W. 4 Mer. and Lsd. 10, Sec. 22, Twp. 36, Rge. 19, W. 4 Mer. (figure 6) and, between Range 23 and 21 west of the Fourth Meridian (figure 7) and west of Range 23 west of the Fourth Meridian (figure 8). The pinchout position is indicated by the zero isolith in figure 18, with the shale unit absent to the west of that line. The shale interval thickens to the east and southeast in the area of study where it attains a thickness of 150 feet.

The Upper Shale Unit is thinner in the north than it is in the south and south-east, as illustrated by the north-south trending sections (figures 10 and 11). Its thickness is 90 feet in the southern part of section FF′ and thins to the north and west by successively losing the upper beds of the unit by facies change into the Horseshoe Canyon basal beds.

The overlying member of this cycle is similar in lithology and log signature to the sand and coarse fraction of the previously discussed cycles D and E, and in addition contains wide spread coal seams that attain considerable thickness. The base of this sandstone and carbonaceous interval is considered as the upper boundary of the Bearpaw Formation in the study area.

V. LOCAL AND REGIONAL INFERENCES

A. Relation to Castor Area

Lines (1963) proposed a two member subdivision for the Bearpaw Formation from outcrop sections along the Battle River and on Paintearth Creek, about 15 miles northeast and north, respectively, of the Castor well. The Young Creek Member consists of 220 feet of argillaceous sandstone and shale marked at the base by a few chert pebbles. Two sandstone beds, each about 50 feet thick were described from this member. The overlying Paintearth Member consists of 180 feet of alternating dark shale and massive sandstone, and the base of the member is marked by a chert pebble bed 3 feet thick. Two 30-foot sandstones were reported by Lines from this member. The lower sandstone was believed to be the equivalent of the Bulwark Sandstone of Slipper (1919) and was reported to be fairly widely distributed in southcentral Alberta (Lines, 1963). Given and Wall (1971) correlated the Bulwark Sandstone and another sandstone interval below the top of the Bearpaw Formation (described as non-marine by Lines), to the Second and First Castor Sandstones respectively on the basis of lithologic similarities and electric log character. It follows on the basis of lithology and electric log character that the Paintearth Member of Lines (1963) is equivalent to those beds in the area of study (including the First and Second Castor Sandstones) that lie between the top of the Bearpaw Formation and the base of the shale unit below the sandstone of cycle D. Thus the sandstone intervals of cycles D and E are equivalent to the Bulwark Sandstone and the upper "non-marine" sand of the Paintearth Member respectively (table 1).

The upper sandstone interval of the Young Creek Member is probably equivalent to the sandy interval of the lower part of cycle D, and the lower sandy interval of the member is probably the equivalent of the sandy zone of cycle B. The lower shale unit of the Young Creek Member seems to be equivalent to the lower shale unit of cycle B, which would probably indicate that cycle B is more developed to the northeast, outside the study area.

B. Relation to Red Deer River Section

The sections of the Bearpaw Formation exposed near Dorothy comprise approximately the upper 225 feet of the formation (Given and Wall, 1971). The sections are located in Sec. 26 and 33, Twp. 26, Rge. 17, W. 4 Mer., and Sec. 28, Twp. 27, Rge. 18, W. 4 Mer. and are included within the area of study (table 2). According to their stratigraphic position and lithologic character the components of the sections described are related to the present study as follows:

1. The dark blue-grey shale and the overlying 20-foot thick, brownish-grey, glauconitic "Dorothy sandstone" (informaly named) of the section are most likely equivalent to the upper sequence of cycle D which

	THESIS AREA		GIVEN & WALL, 1971.	LINES, 1963.
	HORSESHOE CANYON FM.		HORSESHOE CANYON FORMATION	HORSESHOE CANYON FORMATION
BEARPAW FORMATION	CYCLE F	UPPER SHALE UNIT	UPPER SHALE UNIT	
	CYCLE E	SANDSTONE UNIT	FIRST CASTOR SANDSTONE	unnamed s.s. unit PAINTEARTH MEMBER
		SHALE UNIT	MIDDLE SHALE	
	CYCLE D	SANDSTONE UNIT	SECOND CASTOR SANDSTONE	" BULWARK " SANDSTONE
		SHALE UNIT	LOWER SHALE UNIT	
	CYCLE C	SANDSTONE		YOUNG CREEK MEMBER
		SHALE UNIT		
	CYCLE B	SANDSTONE UNIT		
		SHALE UNIT		
	CYCLE A	SANDSTONE		
		SHALE UNIT		
	JUDITH RIVER FORMATION		BELLY RIVER FORMATION	BELLY RIVER FORMATION

Table 1. Relation of outcrop sections and core of the Bearpaw and adjacent Formations in Castor area to the subdivisions of the present study.

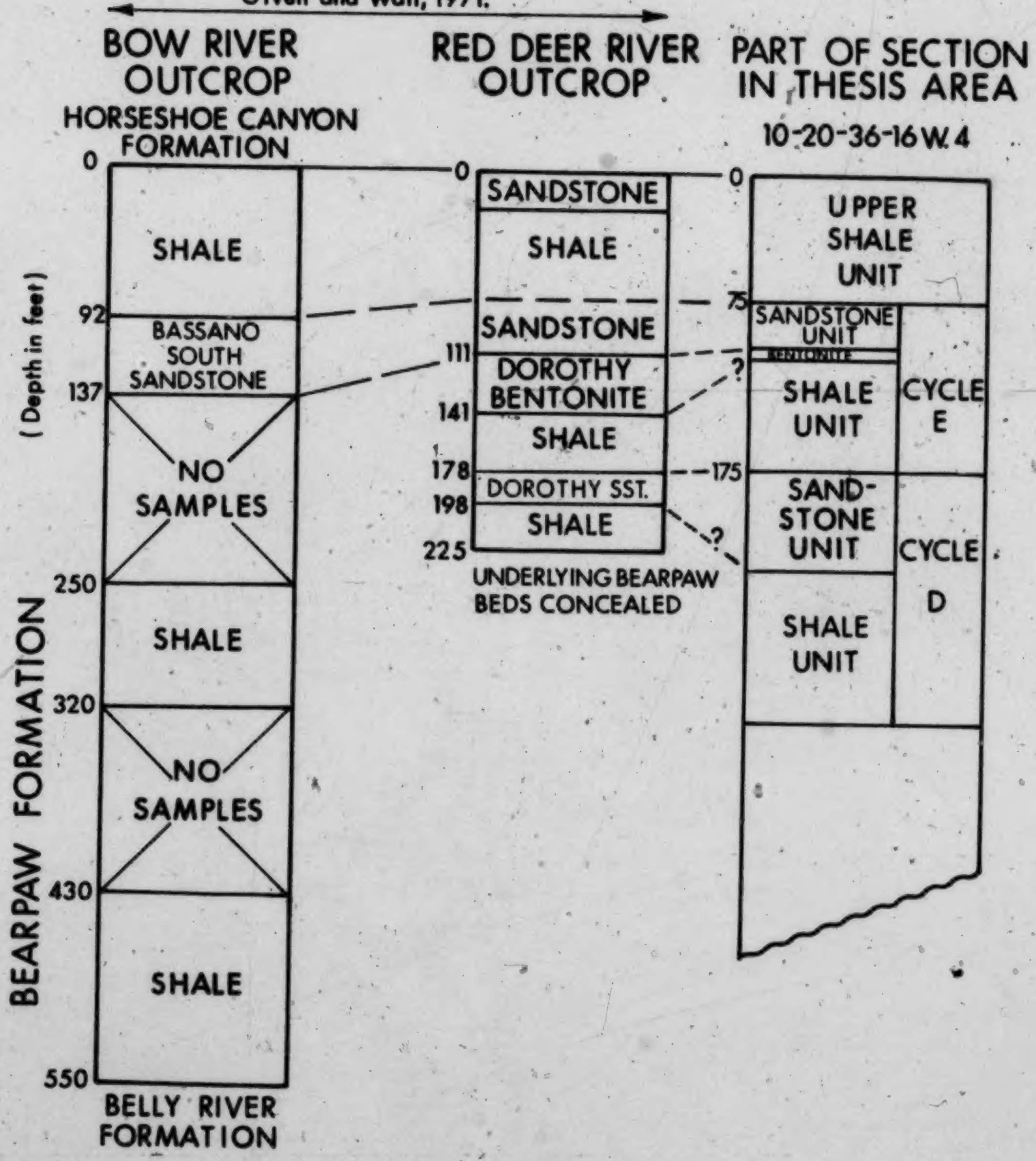

Given and Wall, 1971.
BOW RIVER OUTCROP
HORSESHOE CANYON FORMATION
RED DEER RIVER OUTCROP
PART OF SECTION IN THESIS AREA
10-20-36-16 W.4
(Depth in feet)
0
SHALE
92
BASSANO SOUTH SANDSTONE
137
NO SAMPLES
250
SHALE
320
NO SAMPLES
430
SHALE
550
BEARPAW FORMATION
BELLY RIVER FORMATION
0
SANDSTONE
SHALE
SANDSTONE
111
DOROTHY BENTONITE
141
SHALE
178
DOROTHY SST.
198
SHALE
225
UNDERLYING BEARPAW BEDS CONCEALED
0
UPPER SHALE UNIT
75
SANDSTONE UNIT
BENTONITE
?
SHALE UNIT
CYCLE E
175
SAND-STONE UNIT
?
SHALE UNIT
CYCLE D

Table 2. Relation between Red Deer River and Bow River outcrop sections to part of the subdivision of the present study.

consists of a lower shale unit and the overlying Second Castor Sandstone. This relationship is established from correlations along the eastern part of section FF' (figure 11) and is illustrated by table 2.

2. The 35-foot arenaceous shale, the overlying 30-foot "Dorothy bentonite", and the sandy base of the overlying 111-foot of brownish-grey silty shale that contains some carbonaceous fragments are most likely equivalent to cycle E. The silty shale at the top is in turn overlain by shale and succeeded by interbanded sandstone and siltstone, with the base of the Horseshoe Canyon Formation being placed at the bottom of the first massive thick sandstone. The shale interval is the equivalent of the Upper Shale Unit earlier described.

C. Bow River Outcrop Sections

Clark (1931) described a 40-foot sandstone on the Bow River in the Bearpaw Formation which he called the "middle sandstone Member". Given and Wall (1971) consider this sandstone to be the same as their informal "Bassano South Sandstone" which Clark (1931) apparently placed at a lower stratigraphic position. Another interval, the Bassano Member of Russell (1950) and Russell and Landes (1940), in the area between the town of Hanna and the Little Bow River is described as consisting of finely banded, brown sandy shales and clayey sandstone. The interval lies in the upper part of the Bearpaw Formation, and is overlain by the basal member of the Edmonton Formation (equivalent to Horseshoe Canyon). The lower part of the member seems to be correlative with the "Bassano South Sandstone" of Given and Wall (1971), and from the present study it can be deduced that it is correlative with the First Castor Sandstone of cycle E that also continues to the south and is most likely equivalent to the Bassano South Sandstone (table 2).

D. Regional Inferences

Figure 19 tentatively illustrates the relationships between the Bearpaw of the present study area and its counterparts in southern Alberta and southwestern Saskatchewan.

Cycle A of this study seems to be equivalent to part of the lower one third of the Lethbridge section with the addition of the Magrath sandstone. The interval is probably the equivalent of part of the lower one third of the Manyberries Member of the Cypress Hills and the Demaine and Sherrard Members of the south Saskatchewan River valley.

Cycles B, C and D are probably equivalent to the Kipp sandstone and the underlying shales of the Lethbridge section and to the Ardkenneth Sand and Beechy Shale Members of Saskatchewan and to the middle part of the Manyberries Member of the Cypress Hills.

The shale unit of cycle E (Middle Shale Unit of Given and Wall, 1971) is probably equivalent to the shales overlying the Kipp Sand of the Lethbridge section. This unit

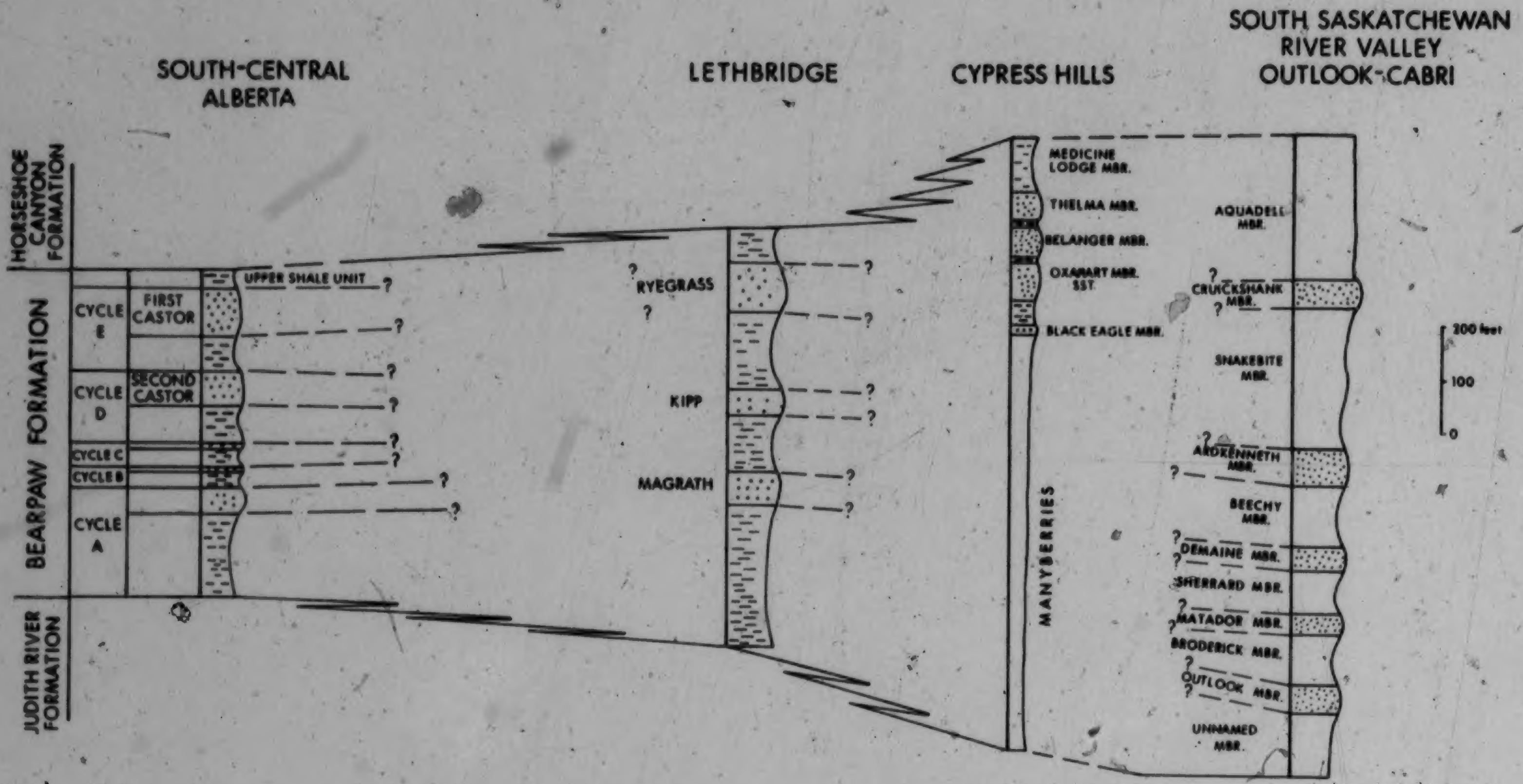

SOUTH-CENTRAL ALBERTA
LETHBRIDGE
CYPRESS HILLS
SOUTH SASKATCHEWAN RIVER VALLEY OUTLOOK-CABRI
HORSESHOE CANYON FORMATION
BEARPAW FORMATION
JUDITH RIVER FORMATION
CYCLE E
CYCLE D
CYCLE C
CYCLE B
CYCLE A
FIRST CASTOR
SECOND CASTOR
UPPER SHALE UNIT
RYEGRASS
KIPP
MAGRATH
MEDICINE LODGE MBR.
THELMA MBR.
BELANGER MBR.
OXARART MBR. SST.
BLACK EAGLE MBR.
MANYBERRIES
AQUADELL MBR.
CRUICKSHANK MBR.
SNAKEBITE MBR.
ARDKENNETH MBR.
BEECHY MBR.
DEMAINE MBR.
SHERRARD MBR.
MATADOR MBR.
BRODERICK MBR.
OUTLOOK MBR.
UNNAMED MBR.
200 feet
100
0

Figure 19. Lithologic correlation of the Bearpaw Formation between the area of study, Southern Alberta and Southwestern Saskatchewan.

is correlative to the upper part of the Manyberries Member of the Cypress Hills and which is the equivalent of the Snakebite Member of the south Saskatchewan River valley as was established by North and Caldwell (1970) from foraminiferal and ammonite zones. The sandy unit of cycle E (i.e. First Castor Sandstone equivalent) is probably the correlative of the Rye Grass Sandstone of the Lethbridge section. This sandstone is probably equivalent to the lower part of the Oxarart Sandstone and the Black Eagle Member of Russell (1950) in Cypress Hills. North and Caldwell (1970) established that the Oxarart Member and the Cruikshank Member are in the *Baculites eliasi* Zone. It follows that the sandy unit of cycle E is probably equivalent to the lower part of the Cruikshank Member of the south Saskatchewan River valley section.

The Upper Shale Unit of the Bearpaw Formation is present in most of the sections and overlies the sands that are equivalent to the upper part of cycle E.

E. Thickness Variations

Figure 20 illustrates the total Bearpaw Formation isopach within the present study area. The formation is thickest in the southeastern and eastern part of the area and thins to the north, northwest and western part of the area. The maximum thickness of the formation in the southeast is 696 feet and the minimum thickness in the northwest is 300 feet. The upper sandstone intervals of the

Bearpaw Formation (cycles D and E) considered as part of the Horseshoe Canyon Formation in the northwestern part of the area.

Thickness of the formation at Castor is 470 feet (Given and Wall, 1971) and to the south it is 575 feet (figure 20). Further south the formation thickens to 740 feet at Keho Lake (Clark, 1931) and at Lethbridge a thickness of 726 is reported (Link and Childerhose 1931). The formation thickens to the east to 1030 feet in southwestern Saskatchewan (Loranger and Gleddie (1953) and it is 900 feet thick in the south Saskatchewan River valley (Caldwell and North 1964).

To the northwest the Bearpaw Formation thins to a thickness of 100 feet according to data from well logs in the Pembina field west of Edmonton (Williams and Burk 1964). West of the area of study only cycles A to C and the lower part of cycle D might be present north of the Bow River, but it would be very difficult to recognize the shales as part of the Bearpaw Formation as they become extremely silty and sandy as illustrated by section DD′ (figure 9). This is probably why the formation is reported to be absent in that part of the west in Alberta (Williams and Burk 1964).

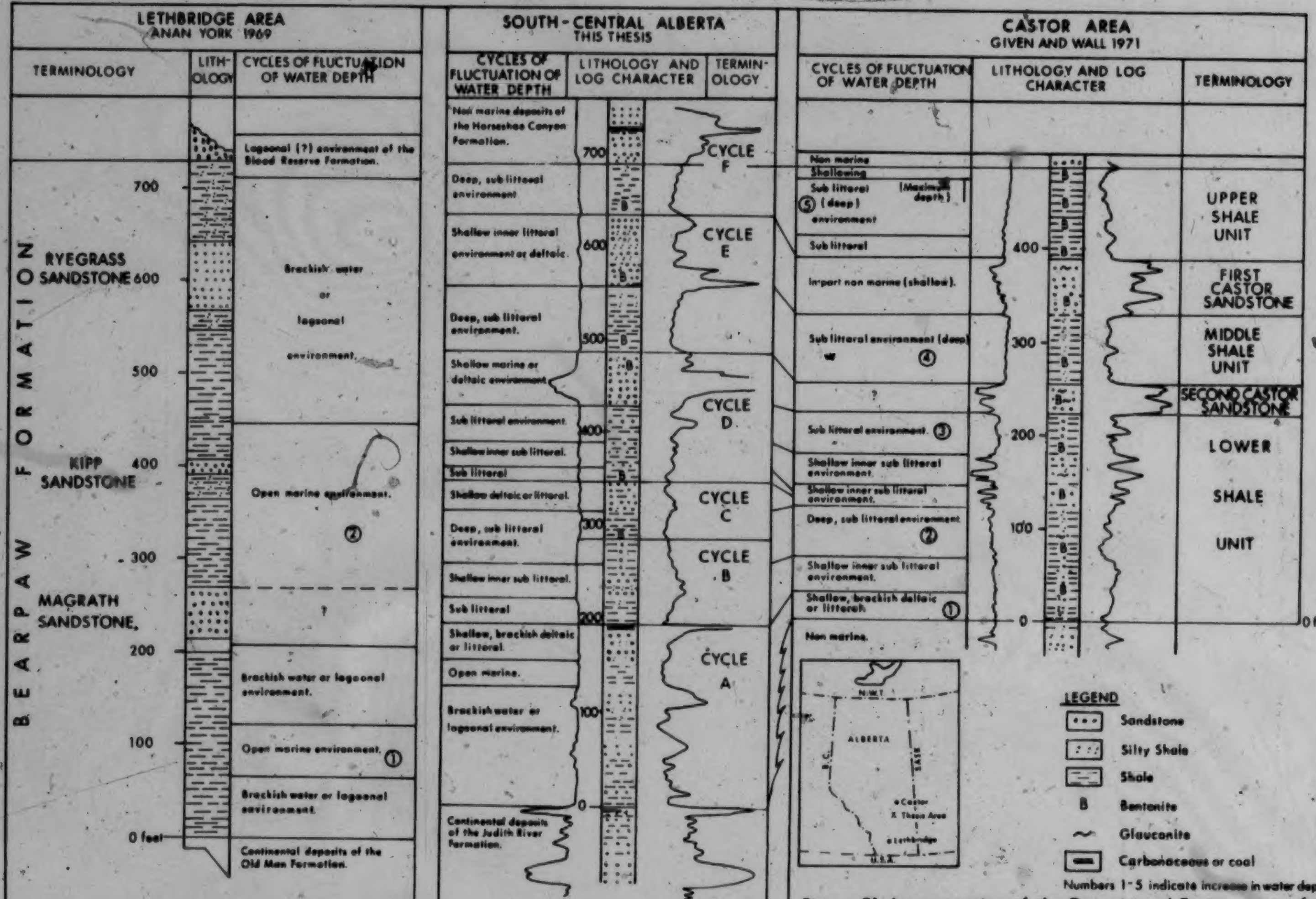
VI. DEPOSITIONAL ENVIRONMENT

Data from which this part of the study is derived is based on the interpretation of the results of the present study, and on the results of forminiferal studies of Given (1969) and Given and Wall (1971) in the Castor area, Anan-York (1969) in the Lethbridge area, on a study by Shepheard and Hills (1970) relating to the depositional environment of the transition zone in the upper part of the Bearpaw Formation southeast of Drumheller, and on the results of studies by Caldwell (1968) and North and Caldwell (1970, 1975) on the formation in the South Saskatchewan River valley.

A. Fluctuation in Water Depth

Figure 21 illustrates the probable environment of deposition of the Bearpaw Formation in southcentral Alberta as interpreted from lithology (thesis area) and from correlation with the results of foraminiferal studies in Castor (Given, 1969 and Given and Wall, 1971) and Lethbridge (Anan-York, 1969) areas. The study area is between Castor and Lethbridge and thus a similarity in the depositional environment of the Bearpaw Formation in the three areas can be expected.

These authors used the dominance of calcareous over arenaceous foraminifera as an indicator of open marine or sublittoral environment of deposition and indicated that the


LETHBRIDGE AREA
ANAN YORK 1969
TERMINOLOGY
LITH-OLOGY
CYCLES OF FLUCTUATION OF WATER DEPTH
BEARPAW FORMATION
RYEGRASS SANDSTONE
KIPP SANDSTONE
MAGRATH SANDSTONE,
700
600
500
400
300
200
100
0 feet
Lagoonal (?) environment of the Blood Reserve Formation.
Brackish water or lagoonal environment.
Open marine environment. ②
?
Brackish water or lagoonal environment.
Open marine environment. ①
Brackish water or lagoonal environment.
Continental deposits of the Old Man Formation.
SOUTH-CENTRAL ALBERTA
THIS THESIS
CYCLES OF FLUCTUATION OF WATER DEPTH
LITHOLOGY AND LOG CHARACTER
TERMINOLOGY
Non marine deposits of the Horseshoe Canyon Formation.
Deep, sub littoral environment
Shallow inner littoral environment or deltaic.
Deep, sub littoral environment.
Shallow marine or deltaic environment.
Sub littoral environment.
Shallow inner sub littoral.
Sub littoral
Shallow deltaic or littoral.
Deep, sub littoral environment.
Shallow inner sub littoral.
Sub littoral
Shallow, brackish deltaic or littoral.
Open marine.
Brackish water or lagoonal environment.
Continental deposits of the Judith River Formation.
CYCLE F
CYCLE E
CYCLE D
CYCLE C
CYCLE B
CYCLE A
CASTOR AREA
GIVEN AND WALL 1971
CYCLES OF FLUCTUATION OF WATER DEPTH
LITHOLOGY AND LOG CHARACTER
TERMINOLOGY
Non marine
Shallowing
Sub littoral ⑤ (deep) environment
(Maximum depth)
Sub littoral
In part non marine (shallow).
Sub littoral environment (deep) ④
?
Sub littoral environment. ③
Shallow inner sub littoral environment.
Shallow inner sub littoral environment.
Deep, sub littoral environment ②
Shallow inner sub littoral environment.
Shallow, brackish deltaic or littoral. ①
Non marine.
UPPER SHALE UNIT
FIRST CASTOR SANDSTONE
MIDDLE SHALE UNIT
SECOND CASTOR SANDSTONE
LOWER SHALE UNIT
0 feet
N.W.T.
ALBERTA
B.C.
SASK.
Castor
X Thesis Area
Lethbridge
U.S.A.
LEGEND
Sandstone
Silty Shale
Shale
B Bentonite
Glauconite
Carbonaceous or coal

Numbers 1-5 indicate increase in water depth.

Figure 21. Interpretation of the Depositional Environments of the Bearpaw Formation from Lithology (Southcentral Albertal) & from Foraminiferal Population (Lethbridge & Castor Areas).

absence of calcareous foraminifera would reflect shallower marine or littoral conditions. On this basis two intervals of open marine conditions were suggested from the Bearpaw in Lethbridge (Anan-York, 1969) and five intervals of increasing water depth from the Formation in Castor (Given, 1969 and Given and Wall, 1971). The remaining part of the formation suggested shallower conditions (deltaic, lagoonal, littoral or brackish water conditions).

A similar interpretation of the depositional environment of Bearpaw sediment is suggested from grain size distribution and lithologic variations (this study). The shale intervals suggest open marine conditions, the silty shale intervals suggest a transition from sublittoral to slightly shallower conditions and the sandstone and carbonaceous intervals suggest inner sublittoral to deltaic conditions of deposition (figure 22). An increase in water depth is reflected by a fining-upward in grain size and shallowing is reflected by a coarsening-upward in grain size.

As indicated previously cycle A of the present study is represented by the basal 34 feet in the Castor Well and is deposited under brackish or deltaic conditions (Given and Wall, 1971). At Castor this interval represents the first inundation of the Bearpaw Sea. This interval is represented by 200 feet of shale and part of the Magrath Sandstone and is correlative to cycle A although sand lenses occur in the lower two thirds of the cycle. The shale below the upper

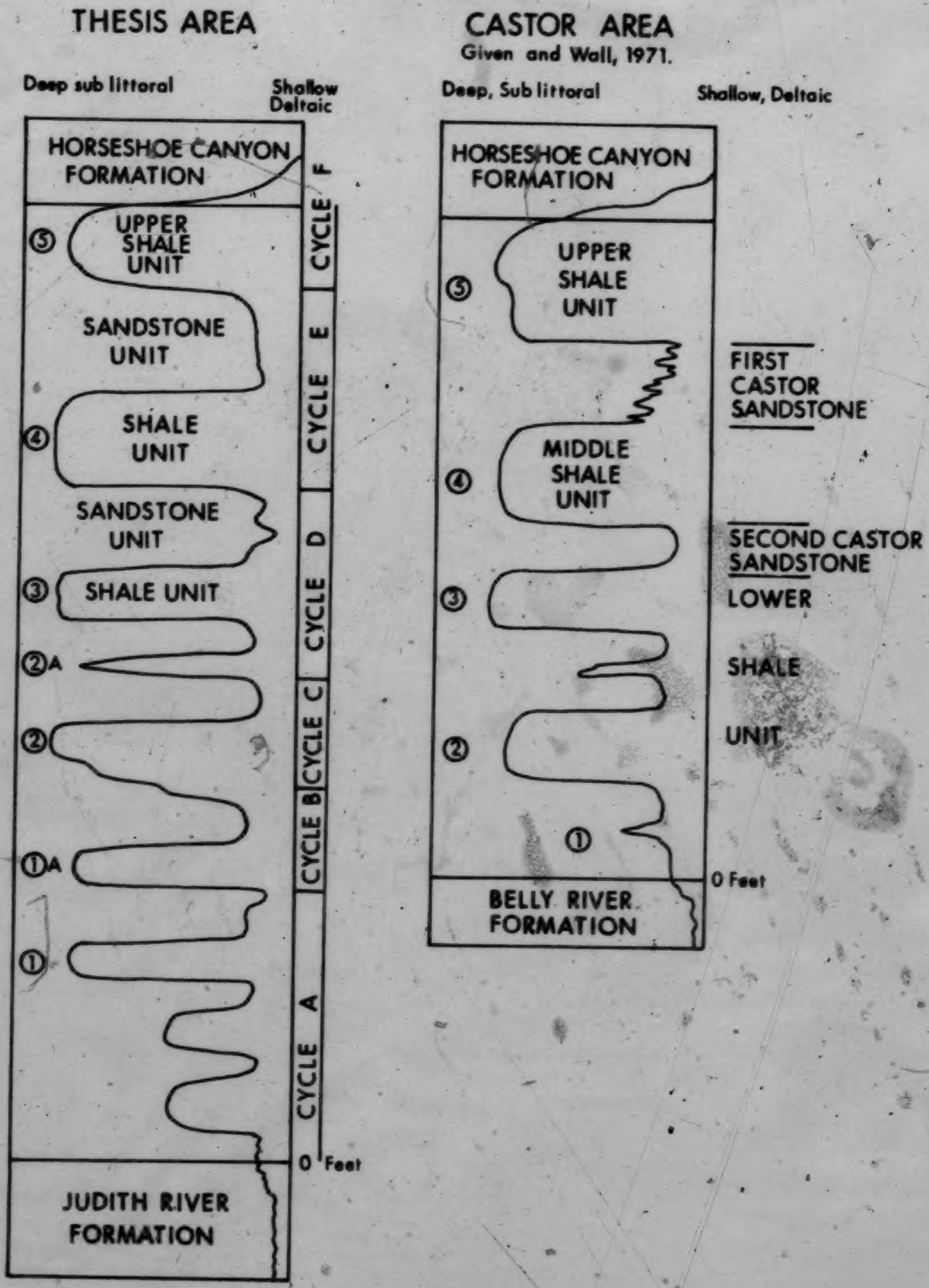

THESIS AREA
Deep sub littoral
Shallow Deltaic
HORSESHOE CANYON FORMATION
UPPER SHALE UNIT
SANDSTONE UNIT
SHALE UNIT
SANDSTONE UNIT
SHALE UNIT
JUDITH RIVER FORMATION
⑤
④
③
②A
②
①A
①
CYCLE F
CYCLE E
CYCLE D
CYCLE C
CYCLE B
CYCLE A
0 Feet
CASTOR AREA
Given and Wall, 1971.
Deep, Sub littoral
Shallow, Deltaic
HORSESHOE CANYON FORMATION
UPPER SHALE UNIT
FIRST CASTOR SANDSTONE
MIDDLE SHALE UNIT
SECOND CASTOR SANDSTONE
LOWER SHALE UNIT
⑤
④
③
②
①
0 Feet
BELLY RIVER FORMATION

Figure 22. Fluctuation of water depth during the deposition of the Bearpaw Formation in Castor and south-central Alberta.

sandy unit of cycle A is equivalent to the shale interval in the lower part of the formation in Lethbridge that was deposited under open marine conditions. The upper part of cycle A reflects a return to deltaic or brackish water deposition similar to conditions in the Lethbridge and Castor areas.

A similar pattern of fluctuation is repeated by the deposition of cycles B and C. The second increase of water depth at Castor is reflected in the thesis area by the deposition of the shales of cycle C after which shallowing occurred and the sands of cycle C were deposited. This was followed by a minor increase in water depth and the shales at the base of cycle D were deposited.

The third major increase in water depth took place during the deposition of the shales below the sandstone of cycle D (Second Castor equivalent). At Lethbridge, marine conditions prevailed during the deposition of these shales and at Castor a sublittoral environment is suggested by the third deepening of the waters of the Bearpaw Sea.

Deposition of the sandstone of cycle D and its equivalent at Castor took place under shallow marine or deltaic conditions as indicated by the presence of carbonaceous material in the interval in a number of wells in the area. This sandstone is equivalent to the Kipp member in Lethbridge which was deposited under open marine conditions.

The fourth increase in water depth is represented by the deposition of the Middle Shale unit in Castor area and by the shale unit of cycle E in the thesis area and by the shales below the Rye Grass Sandstone member in the Lethbridge area.

Return to shallow inner littoral conditions took place during the deposition of the sandstone of cycle E, the First Castor Sandstone (Castor area) and the Rye Grass Sandstone in Lethbridge.

The fifth major inundation by the Bearpaw Sea deposited the Upper Shale Unit at Castor, the shale unit of cycle F in southcentral Alberta and the shale overlying the Rye Grass Sandstone at Lethbridge. The maximum depth reached by this inundation took place during the deposition of the shale 10 feet below the top of the Bearpaw formation in the Castor well as indicated by Given and Wall (1971).

Therefore five major increases in water depth are suggested during the deposition of the Bearpaw Formation in southcentral Alberta. Two additional minor increases in water depths are suggested for the shale interval of cycle B and the basal shales of cycle D, as illustrated by figure 21. The two minor fluctuations are represented in the Castor area by thin shale intervals that were deposited under shallower conditions, and by a shale interval in Lethbridge that was deposited under open marine conditions.

B. Cyclicity

A repeated pattern of deposition can be recognized in the three areas discussed above and at least three types of deposits are seen within the sequence of Bearpaw sediments in southcentral Alberta. A somewhat deep sublittoral deposit is illustrated by interbedded shales and silts that constitute the fine fraction of each cycle. A shallower littoral or deltaic deposit is illustrated by interbedding of sands and silts of the coarse fraction of the cycle, where the distribution of sandstone could possibly imply the effect of current activity. Finally the coal seams and carbonaceous deposits and their underclays are indicative of even shallower swampy environment of the cycle.

The repetition of the cycle is demonstrated completely by cycles A, D, E, and F of the study and partially by cycles B and C that were interrupted either by decrease in sediment supply or increase in water depth. This cyclicity is also illustrated in the Castor and Lethbridge areas by repeated alternations of littoral and sublittoral deposits as illustrated by the absence or presence of calcareous foraminifera.

Cyclicity is also persistent in the transition zone below and above the boundary of the Bearpaw and Horseshoe Canyon Formations. Shepheard and Hills (1970) investigated the environment of deposition of the transition zone ten miles southeast of Drumheller in Alberta. Their study concentrated on the uppermost part of the Bearpaw Formation and the lower part of the Horseshoe Canyon Formation and thus included the sandstone of cycle E and the Upper Shale Unit of the present study. According to their findings the deposition of the sediments of the transition zone was associated with the movements of a shoreline eastward across southern Alberta and that likely a series of deltaic complexes existed along the margin of the sea in front of a broad coastal plain. Six cycles of characteristic deposits were illustrated by their study with each sequence of sediments being deposited within a particular part of the delta environment. In particular their unit "BP" which is equivalent to the Upper Shale Unit "... resembles very closely the prodelta and delta front deposits of most of the modern deltas deposited offshore of the subaerial portions of the deltas" (Shepheard and Hills, 1970, p.199). The prodelta deposits are fine grained with dominant structures being laminae and thin interbeds of silt and shale in the Mississippi Delta (Fisk, 1961). The remaining five cycles of Shepheard and Hills (1970) are in the lower part of the Horseshoe Canyon Formation and consist of distributary channel and marginal channel deposits, beach-barrier complex, open bay mud flat deposits and open bay deposits. One important sequence, that of the distributary channel and marginal channel deposits consists of major distributary sand deposits overlain by clays and silts of the marginal swamp and back-swamp deposits and finally coals of the marsh deposits are found at the top of the sequence. Lateral gradation of the deposits of this sequence is indicated by Shepheard and Hills (1970) and a similar gradation is also persistent between the shales of the unit "BP" and the sands of unit "E1".

C. Cycle A

The present study has illustrated the distribution and geometry of this cycle and the results are now discussed in relation to environmental implications.

The lower shale unit of cycle A is predominantly wedge-shaped and is thick in the east (200 feet) and thin in the west (70 feet) in southcentral Alberta. The unit is not present to the northeast of the area and probably grades laterally into the upper beds of the Belly River Formation in the Castor area. The unit is characterized by the presence of laminae of silt interbedded with the shale and occasional silty sandstone interbeds. The presence of silt laminae within the shale is similar to the prodelta and delta front deposits of modern deltas described by Fisk (1961) and Coleman and Gagliano (1964) in the Mississippi deltaic complex. The lower shale unit of cycle A grades upwards into siltstone and silty sandstones that grade into a sandstone bed towards the upper part of the cycle. This coarsening-upward is also another characteristic of modern deltaic deposits prograding in a seaward direction. Further progradation is illustrated by the presence of clay and the overlying coal seam at the top of cycle A which resemble deposits of the swamp and marsh environment of modern deltas.

The sandstone of cycle A is thicker in the west (closer to the source) where more than 140 feet are encountered, and thins out to the east where it is less than 10 feet thick. It is distributed along four major eastwest trending thick areas (figure 14) that thins to the east and southeast in the form of lobes. This distribution is similar in areal extent with the distribution of channel deposits and their complex distributaries and that of the thin areas resembles sheet-like deposits of the interdistributary area. The channel sands are probably similar in distribution to bar finger sands and silts of the Mississippi delta (Fisk, 1961) but have a more complex trend of distribution that probably indicates more active shifting of streams during deposition.

D. Cycle E

This unit represents the fifth major coarsening-upward sequence in the Bearpaw Formation and consists of a lower shale unit and an upper sandstone unit. The lower shale unit is generally bentonitic and silty with lenses of silt throughout most of the interval across the area of study. The presence of silt is also indicated by Given and Wall (1971) in their core description. The dominance of silt is recognized in the basal beds of the unit, decreases in the middle part of the shales and increases again in the upper part of the shale interval. This distribution of the silt indicates a slow incoming transgression from the east that increases during the deposition of the middle part of the shale interval where the silt fraction is not dominant and then a return to prodelta shales and silts during the deposition of the upper part of the shale interval. This pattern of deposition is further illustrated by the geometry of this unit, typically wedge-shaped, and thinning to the north, west and southwest of the study area.

The base of the sandstone of cycle E is silty and contains shale laminae that grade upwards into a 39-foot sandstone which is medium grained and contains occasional carbonaceous lenses. This is overlain by an 18-foot sandstone interval that also contains carbonaceous stringers. Carbonaceous stringers become more persistent in the western part of the area and this is associated with a thicker distribution of the sandstone interval (figure 8). The sandstone is distributed along six major thick trends separated by areas where the sandstone is thin and sheet like in distribution (discussed earlier). The sandstone distribution within the thick trends along with the coarsening-upward character of the deposit resembles a similar pattern of deposition as the sandstones of cycles A and D and strongly suggests a relation to bar finger sands. The presence of carbonaceous lenses and stringers suggests shallowing and shifting of streams and the existence of marsh environment. Caldwell (1968) indicated the presence of wood fragments (of all sizes) imbedded into the sands of the

Bearpaw Formation of the Saskatchewan River valley and other types of plant fragments, and indicated that deposition of the formation took place under shallow water conditions, and that the clays were deposited at no greater depth than the sands. Caldwell adds (page 66) "... The clays are anything but "pure" clays, and the great bulk of them contain a high profusion of silt ... 35 to 45 per cent silt."

E. Conclusion

The information presented in this study show that cyclicity is an important factor in the deposition of the Bearpaw Formation in southcentral Alberta and neighbouring areas. The cycles are similar in gross features such as lithology, grain size distribution and geometry with a dominant coarsening-upward character. The shale units of the cycles are wedge-shaped and contain a high proportion of silt grading vertically and laterally into the coarser sandy part of the cycles. The sandstone units of the cycles, their character, distribution and areal extent indicate the predominance of stream activity in their deposition. The study also illustrated that carbonaceous lenses and coal seams with a lagoonal clay beneath are present at the top of cycles A, C, D, E and F of the formation.

These findings illustrate that the cycles of the Bearpaw Formation were deposited under shallow marine deltaic conditions similar (with slight variation) to deposits of the Mississippi delta (described by Fisk, 1961).

This environment persisted during the deposition of the unit "E1" of the lower part of the Horseshoe Canyon Formation of Shepheard and Hills (1970). The fine fraction of the cycles represent prodelta and delta front shales and silts and the coarse fraction respresents bar finger sands and sheet sands of the distributary mouth bar and interdistributary sediments of the delta complex. Moreover deltaic lobe progradation with avulsion and compaction should be considered as mechanisms for the cyclicity of the Bearpaw sediments in the study area.

VII. PALEOGEOGRAPHY

The last major transgression during the Late Cretaceous (late Campanian to early Maestrichtian) time penetrated Alberta north of the Peace River arch (Wall, 1973, 1975), and as far west as the edge of the foothills in southern Alberta and Montana (Williams and Stelck, 1975), (figure 23), depositing the Bearpaw Formation. Maximum flooding took place in Alberta at the time of *Baculites reesidei* (Rosene, 1972) in the latest Campanian. This is also the case in the Rocky Mountain states (McGookey *et al*., 1972). A connection is suggested between the western interior, Greenland and Europe from close affinities of *Scaphites quadrangularis* (which occurs in the *B. reesidei* zone) to eastern forms (Jeletzky, 1971a; Birkelund, 1965).

Sedimentary infilling of the basin from the west perhaps with accompanying uplift of the Mackenzie Mountain region (Williams and Stelck, 1975) forced the sea to retreat from the interior of the continent. The record of this transgressive and regressive sequence in the sediments discussed in the present study indicates the shoreline position, or at least the shoreline phase, in southcentral Alberta.

Figure 13 indicates that the first inundation by the Bearpaw Sea reached a position close to the foothills region, but probably not further west than Rge. 8, W. 5 Mer. in the south and probably not further west than Rge. 10, W.

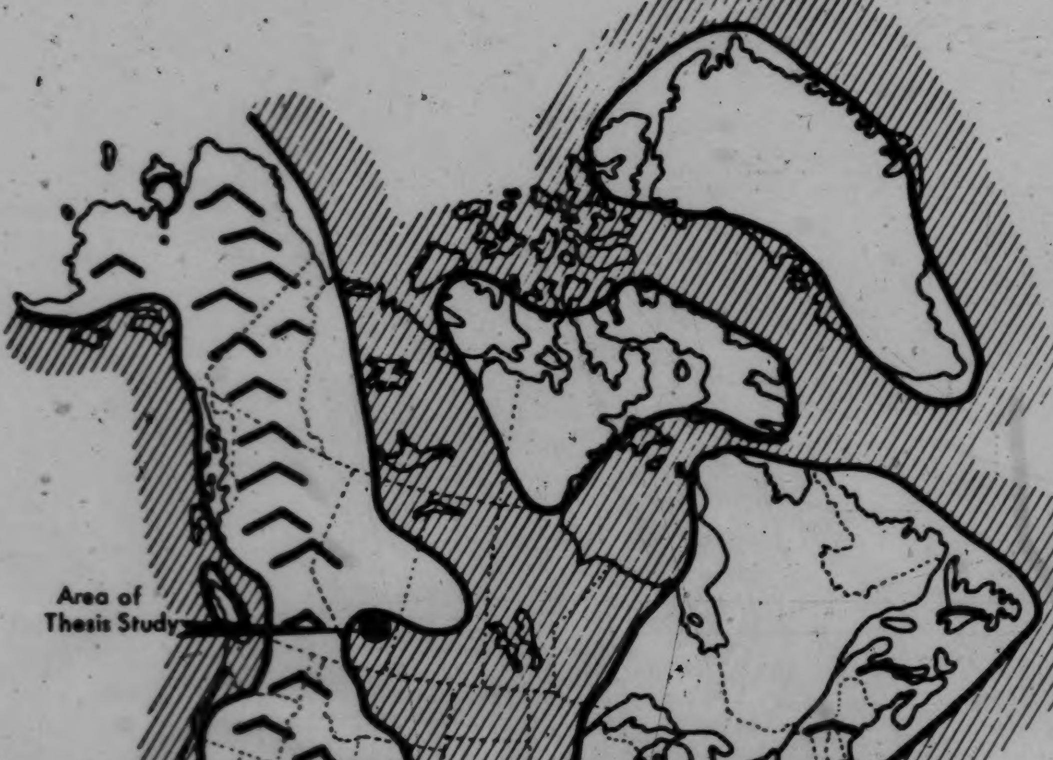

Area of
Thesis Study
MILES
0 200 400 600 800
Early Maestrichtian Seas
B. baculus time

Figure 23. Map showing extent of early Maestrichtian seas at the time of Baculites baculus (adapted from Williams and Stelk, 1975).

5 Mer. in the north, as indicated by the sandy and silty nature of the shale interval of cycle A.

The sandy interval (figure 14), of cycle A indicates that the shoreline must have regressed to the east of Rge. 17, W. 4 Mer. in the south and to the east of Rge. 19, W. 4 Mer. in the north as suggested by the coal seam present at the top of the sandy interval and the deltaic progradation illustrated by the extension of trends into the eastern part of the map.

The intermediate pulses of cycles B and C indicate two fluctuations illustrated by their similar distribution to cycle A. Distribution of the prodelta shales of cycle D indicate two more intertonguing transgressions and regressions. The transgressions did not reach as far west as the previous inundations as illustrated by the sandy nature and thinning of the shales to the west and north (figures 6 to 11). The shoreline position probably remained east of Rge. 4, W. 5 Mer. within the area of study. The shoreline was forced back and shallow lagoons formed within the interdistributary areas and swamps advanced towards areas previously occupied by the shore. Coal was formed on top of silts and sands and the waters of the sea must have withdrawn, probably to the east of Rge. 19, W. 4 Mer.

During the deposition of the shales below the sands and coals of cycle D, the water came back well into the region west of Rge. 1 W. 5 Mer. but probably not too far west of that position as the shales become silty and sandy along section DD' (figure 9).

The filling up of the basin during the deposition of the Second Castor Sandstone pushed the sea back to the east gradually, just west of the most eastern deltaic branches shown in figure 15.

The sea again transgressed over the area as shown by the shales of cycle E in figure 16 as far as the zero isolith line that runs across the area in a northeast to southwest direction. After the basin filled up and the First Castor Sandstone was deposited, the sea retreated to the east close to Rge. 19, W. 4 Mer. (figure 17), a final transgression of the sea over the area produced the sediments of the Upper Shale Unit.

The Upper Shale Unit represents the prodelta shales and silty shales of the final transgression of the Bearpaw Sea (figure 18), with the zero isopach line east of Rge. 22, W. 4 Mer. where the unit pinches out representing the shoreline position. As the deltaic deposits of the Horseshoe Canyon prograded to the east the sea was pushed back to the east and south of the area. The regression was gradual and the main direction of retreat appears to be slightly to the southeast as reflected by the orientation of the isolith lines of the Upper Shale Unit.

The paleogeography of the area during the deposition of the Bearpaw was dominated by pulsating shoreline conditions that were affected by deltaic deposition, with sediments supplied rapidly from the west and deposited into a slowly subsiding basin. If the rate of sediment supply and water discharge are constant and relatively high during a period of time then long linear sand bodies are common and build progressively in a seaward direction (Coleman, 1976). Another factor that can be suggested for the long linear trending sand bodies of cycle A is the probable presence of linear structural east-west trending channel features. These channel features might have affected the direction of progradation of the deltaic cycles of the Bearpaw Formation in the study area.

VIII. CONCLUSION

Six cycles of deltaic deposits are suggested for the Bearpaw Formation in southcentral Alberta and neighbouring areas. In ascending order the cycles are named A, B, C, D, E and the Upper Shale Unit. Each cycle consists of a coarsening-upward sequence (shale, silts and fine to medium grained sandstones) that represents a gradation from prodelta shales at the base to silts and sands of the delta front and distributary mouth bar facies. Coal is present at the top of cycles A and C, and the lower part of D. Carbonaceous stringers are present at the top of the sands of cycle E, and in the middle of the sands of cycle D. The presence of coal is indicative of shallow lagoonal or marsh and swamp environments of the delta.

Interruption of the cycles such as B and probably C and the sharp contact at the top of the cycles (especially A and D) indicates by comparison with faunal evidence that deeper conditions prevailed and the sea transgressed over the area. Seven pulses of transgressive nature are interpreted to have occurred during the Bearpaw depositional history as suggested from the presence of an additional cycle in cycle D (considered as one cycle as both join and are not recognized in the north and west as separate).

As the depth of water is interpreted to be close to 150 feet (Caldwell, 1968), infilling of the basin forced the waters of the Bearpaw Sea to retreat to a more easterly position, and deltaic subenvironments prograded vertically on previously deposited ones to form the characteristic coarsening-upward sequence.

Detailed correlations indicate that the lower contact between the Bearpaw Formation and the underlying Judith River Formation rises to the west and is diachronous, as the top beds of the Judith River gradually replace the basal beds of the Bearpaw Formation. In detail the contact is strongly interfingering as seen in well logs.

The Bearpaw Formation is much thinner in the northwest (300 feet) than it is in the southeast (695 feet), with the decrease caused by gradual thinning of the shale units to the northwest and the pinching out of the two shale units above and below the First Castor Sandstone.

The seven pulsating transgressions of the Bearpaw Sea indicate that the paleogeography was unstable and fluctuating. Environmental variations that are present in the sediment record above the Bearpaw Formation indicate that the climate was humid and sub-tropical, perhaps like that of the Mississippi Delta area in the Gulf Coast at present (Shepheard and Hills, 1970). A close similarity was found between the transition zone above the Upper Shale Unit and Bearpaw sediments, suggesting that a similar interpretation is reasonable for the depositional environment of the Bearpaw Formation.

The upper boundary of the Bearpaw Formation has been described as diachronous by many authors. As suggested by evidence from this study (thinning of sand units to the east and south, and facies change in the upper part of the formation) the Bearpaw Formation of southcentral Alberta grades laterally and vertically upwards into the Horseshoe Canyon Formation and that the upper boundary of the Bearpaw Formation is older in the southeast than it is in the northwest in the study area.

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APPENDIX A

Well Standard Symbols

APPENDIX A

WELL STANDARD SYMBOLS

WELL TYPE	POST DEVONIAN	PRE MISSISSIPPIAN
LOCATION	○	
OIL WELL	●	●
GAS WELL	☼	☼
OIL & GAS WELL	✸	✸
ABANDONED OIL WELL	⌀	⌀
ABANDONED GAS WELL	✲	⊛
GAS INJECTION WELL	⋎G	⋎G
DUAL GAS WELL	☼	✺
WATER INJECTION WELL	⋎W	⋎W
SALT WATER DISPOSAL WELL	○SWD	○SWD
WATER SUPPLY WELL	⋎WS	⋎WS
DRY & ABANDONED	✧	⊗
SALT WATER SUPPLY	⅄S	
POTASH	¤	
CORE HOLE	◎	
GAS STORAGE	○	
POST DEVONIAN OIL WELL non productive in pre-mississippian		⊕
POST DEVONIAN GAS WELL non productive in pre-mississippian		⊛

APPENDIX B

Tops Listing

* = concealed by surface casing

E = unit is part of the Edmonton Group

ND = not distinguished

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-09-25-17W4	2843	970	850	720	685	528	425*	*
11-21-25-17W4	2880	1027	916	795	748	580	480*	*
10-28-25-17W4	2877	1057	912	785	760	596	484*	*
10-33-25-17W4	2884	1030	937	816	777	616	505	*
08-13-25-18W4	2948	1131	1004	885	842	683	564*	*
10-15-25-18W4	2943	1142	1016	902	858	702	570	*
10-18-25-18W4	2934	1148	1016	910	874	720	580	490
10-20-25-18W4	3015	1281	1127	1025	958	808	693	583
10-08-25-19W4	3092	1369	1249	1140	1086	930	792	706
12-11-25-19W4	3093	1370	1238	1131	1060	919	784	898
10-13-25-19W4	3084	1343	1216	1120	1069	892	768	885
10-17-25-19W4	3037	1340	1200	1092	1040	889	751	858
08-18-25-19W4	2984	1298	1159	1080	1013	844	728	870
07-14-25-20W4	3039	1340	1244	1143	1088	939	803	760
10-16-25-20W4	2994	1307	1298	1118	1057	908	771	724
08-16-25-20W4	2872	1300	1200	1108	1050	870	768	721
08-18-25-20W4	2982	1408	1244	1132	1070	924	801	773
04-11-25-21W4	3024	1480	1299	1205	1151	975	882	880
14-13-25-21W4	2893	1440	1270	1188	1110	952	848	813
08-14-25-21W4	3089	1515	1370	1288	1207	1088	949	920

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-20-25-21W4	3020	1500	1349	1243	1200	1057	940	830
04-13-25-22W4	2921	1382	1282	1188	1148	998	877	870
10-14-25-22W4	2963	1427	1320	1210	1183	1040	928	920
08-15-25-22W4	2948	1450	1340	1222	1210	1084	980	931
10-18-25-22W4	2951	1481	1390	---	1239.5	1098	990	947
11-20-25-22W4	3220	1877	1682	1607	1540	1405	1270	1262
10-12-25-23W4	2918	1600	1402	1343	1287	1127	1020	990
08-18-25-23W4	3088	1920	1707	1631	1585	1421	E	1341
08-21-25-23W4	3076	1880	1850	1680	1521	1363	E	1291
10-18-25-24W4	3020	1882	1898	1614	[illegible]	1408	E	1344
08-16-25-24W4	3006	1870	1720	1642	1578	1437	E	1360
11-13-25-25W4	2989	1884	1723	1639	1608	1446	E	1361
08-14-25-25W4	3012	1810	1784	1688	1582	1480	E	1420
08-20-25-25W4	3071	2037.8	1911.2	1842	1893	1630	E	1595.8
08-11-25-26W4	3118	2148	2014	1984	1867	1730	E	1690
08-21-25-26W4	3130	2224	2078	2017	1883	1780	E	1740
08-08-25-27W4	3340	2701	2550	2480	2418	2280	E	2214
11-35-25-27W4	3147	2405	2240	2180	2130	1941	E	1900
08-20-25-28W4	3522	3140	2883	2818	2847	2703	E	2680
10-23-25-28W4	3447	2821	2740	2684	2620	2477	E	2439

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-13-25-28W4	3620	3368	3157	3110	3032	2880	E	2850
11-23-25-28W4	3603	3320	3170	3118	3060	2920	E	2880
14-13-25-01W5	3558	3433	3241	3170	3122	2978	E	2940
08-14-25-01W5	3554	3450	3260	3174	3140	2953	E	2970
05-22-25-02W5	4137	4402	4200	4138	4073	3930	E	3915
10-24-25-02W5	3947	4147	3942	3877	3834	3670	E	3660
11-10-25-03W5	3892	4874	4823	4459	4428	4280	E	ND
08-11-25-03W5	3881	4844	4474	4415	4338	4173	E	4115
11-35-25-03W5	4288	4940	4708	4823	4562	4415		
08-27-25-04W5	3895	5212	5080	5000	4851	4799		
06-04-26-17W4	2940	1088	930	86[illegible]	828	678	550*	*
10-08-26-17W4	2928	1110	892	865	820	667	550	*
08-20-26-17W4	3057	1241	1146	1060	1010	864	721	650
07-13-26-18W4	3087	1270	1170	1068	990	863	739	635
10-18-26-18W4	3135	1388	1304	1214	1170	1003	880	800
11-22-26-18W4	3302	1550	1442	1345	1288	1149	1028	934
10-23-26-18W4	3218	1483	1330	1220	1170	1007	895	810
05-10-26-19W4	3144	1512	1401	1300	1238	1084	940	800
05-20-26-19W4	3203	1591	1490	1359	1300	1140	1013	845
05-21-26-19W4	3245	1589	1488	1385	1330	1181	1040	970

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-25-26-19W4	3316	1917	1541	1447	1393	1232	1105	1041
10-14-26-20W4	3147	1530	1418	1317	1260	1104	990	910
10-15-26-20W4	3122	1513	1382	1308	1243	1080	930	873
07-16-26-20W4	3132	1515	1398	1310	1262	1088	943	905
10-18-26-20W4	3048	1460	1340	1249	1200	1035	870	881
08-13-26-21W4	3083	1488	1380	1282	1234	1073	917	890
10-14-26-21W4	3138	1630	1483	1388	1340	1171	1101*	*
07-15-26-21W4	2982	1418	1324	1230	1162	1030	*	*
08-17-26-21W4	2870	1322	1248	1140	1117	980	760	858
04-18-26-21W4	2840	1407	1238	1127	1110	959	780	850
15-12-26-22W4	2882	1418	1259	1192	1121	974	782	852
10-15-26-22W4	3028	1577	1471	1404	1341	1237*	980	1059
07-19-26-22W4	2898	1514	1340	1283	1228	1110	990	950
08-17-26-22W4	2873	1550	1353	1281	1226	1118	850	972
10-09-26-23W4	2814	1594	1398	1332	1284	1158	910	1080
10-11-26-23W4	2858	1529	1394	1307	1270	1114	900	1040
07-12-26-23W4	2851	1546	1394	1298	1248	1085	829	1012
05-15-26-24W4	3008	1917	1754	1675	1637	1490	1300	1438
11-26-26-24W4	3030	1911	1780	1730	1670	1497	1340	1448
10-29-26-24W4	3047	1984	1800	1740	1684	1510	1328	1438

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-30-28-24W4	3117	2020	1855	1818	1760	1820	1300	1585
07-25-28-25W4	3068	2052	1888	1814	1760	1811	1340	1500
10-26-28-25W4	3104	2047	1886	1830	1770	1824	1397E	1685
10-27-28-25W4	3081	2053	1906	1840	1780	1625	1410E	1580
07-28-28-25W4	3128	2082	1824	1868	1818	1883	1415E	1610
10-18-28-27W4	3312	2720	2580	2535	2473	2337	2140	2300
10-22-28-27W4	3165	2551	2376	2326	2276	2135	1939E	2075
08-20-28-28W4	3635	3310	3114	3057	3012	2876	2737E	2830
08-21-28-28W4	3533	3180	2970	2936	2862	2730	2580E	2712
07-08-28-29W4	3562	3452	3260	[illegible]	3140	3010	2885E	2873
11-10-28-29W4	3585	3460	3261	[illegible]	3140	3032	2880E	2884
11-12-28-29W4	3610	3342	3182	[illegible]	3080	2941	2760E	2860
06-24-28-29W4	3633	3405	3219	[illegible]	3090	2969	2760E	2930
15-16-28-01W5	3815	4190	3980	[illegible]	3324	3647	3290E	3580
08-21-28-01W5	3717	3820	3580	[illegible]	3458	3310	E	3610
10-22-28-01W5	3887	3760	3485	[illegible]	3390	3205	3050E	3245
10-24-28-01W5	3574	3527	3320	[illegible]	[illegible]	[illegible]	2938E	3025
07-28-28-02W5	3815	4231	4035	3876	[illegible]	3780	3808	3774
10-34-28-04W5	4265	5580	5263	5238	5157	5020E		5072
08-26-27-13W4	2840	872	580	500	--	--	--	-- *

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
08-06-27-14W4	2647	710	520	532	417	--	--	-- *
08-01-27-15W4	2718	895	878	503	--	--	--	-- *
08-21-27-15W4	2811	934	818	880	812	478	--	-- *
08-25-27-16W4	2803	1034	817	820	745	617	--	-- *
07-26-27-16W4	2870	1184	1038	934	875	740	624	580*
11-31-27-16W4	3061	1290	1168	1076	989	890	765	650
11-20-27-17W4	2820	860	788	677	585	455	--	-- *
11-33-27-17W4	2792	1076	941	850	758	636	521	410
10-28-27-18W4	2853	950	632	750	685	523	--	-- *
10-27-27-18W4	2848	950	841	756	667	534	--	-- *
08-29-27-18W4	2748	1127	976	893	822	--	--	-- *
08-08-27-19W4	2666	1318	1190	1110	1038	881	-- *	-- *
10-17-27-19W4	2868	1318	1162	1089	1078	880	-- *	-- *
08-19-27-19W4	2792	1252	1152	1087	1010	830	--	-- *
15-13-27-20W4	2768	1218	1105	1040	975	775	658	610*
14-15-27-20W4	2771	1250	1108	1050	965	765	665	632
08-16-27-20W4	2732	1260	1080	1019	940	750	650	632
16-16-27-20W4	2726	1270	1092	1030	950	783	665	667
10-12-27-21W4	2770	1312	1128	1041	988	628	E	775
07-14-27-21W4	2801	1178	880	930	650	670	-- E	638

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-18-27-21W4	2614	1320	1040	988	917	732	E	690
11-16-27-22W4	2661	1390	1200	1140	1020	934	790E	852
10-20-27-22W4	2626	1531	1370	1308	1247	1110	908E	1034
10-28-27-22W4	2791	1528	1367	1300	1218	1097	939E	1080
07-30-27-22W4	2682	1667	1430	1368	1280	1180	840E	1080
08-18-27-23W4	2780	1632	1388	1334	1267	1150	880E	1080
07-30-27-23W4	2853	1750	1523	1450	1400	1257	1100E	1195
07-28-27-24W4	2908	1610	1616	1580	1500	1350	1170E	1270
08-26-27-24W4	2842	1866	1667	1560	1556	1400	1336E	1353
10-28-27-24W4	2913	1890	1680	1580	1567	1398	1223E	1340
10-30-27-24W4	2871	1880	1781	1703	1650	1512	1264E	1463
11-11-27-25W4	3011	2081	1858	1800	1748	1570	1342E	1516
11-24-27-25W4	2963	1872	1760	1730	1663	1533	1330E	1478
11-31-27-25W4	3010	2130	1986	1934	1896	1774	1580E	1700
11-18-27-26W4	3085	2470	2233	2185	2137	2006	1642E	1970
08-14-27-27W4	3161	2601	2380	2336	2260	2158	2030E	2136
07-15-27-27W4	3203	2540	2480	2400	2369	2335	2085E	2203
07-22-27-27W4	3200	2858	2481	2400	2350	2218	2068E	2190
11-28-27-27W4	3274	2830	2608	2541	2478	2357	2230E	2240
07-11-27-28W4	3365	2863	2780	2740	2646	2646	2418E	2520

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-14-27-28W4	3372	3033	2769	2727	2661	2580	2417E	2528
11-02-27-29W4	3648	3536	3338	3284	3260	3087	2808E	3048
10-35-27-29W4	3711	3634	3480	3380	3320	3148	2880E	3105
07-18-27-01W5	3678	4178	3826	3850	3810	3854E	3524E	ND
08-20-27-01W5	3788	4078	3810	3740	3708	3848E	3432E	ND
11-21-27-01W5	3745	3980	3720	3636	3588	3400E	3310E	ND
11-22-27-01W5	3838	3886	3430	3384	3310	3144E	2877E	ND
11-24-27-01W5	3878	3587	3343	3278	3236	3070E	2850E	ND
10-22-27-02W5	3988	4400	4188	4117	4038	3810E	3827E	3838
16-23-27-02W5	4030	4383	4187	4122	4087	3807E	3887E	ND
06-24-27-02W5	3866	4280	4100	4040	3988	3830E	3690E	ND
09-25-27-02W5	3938	4344	4080	3980	3837	3768E	3619E	ND
08-30-27-02W5	4031	4884	4418	4370	4288	4121E	4088E	ND
04-22-27-03W5	4159	5073	4772	4740	4670	4490E	4388E	ND
10-26-27-03W5	4181	4947	4782	4730	4643	4850E	4403E	4864
10-12-27-04W5	4202	5236	5082	4865	4950	4808E	4730E	4928
05-18-27-04W5	4266	5834	5820	5800	5488	5370E	5283E	ND
10-08-28-18W4	2883	1040	900	778	700	--	--	-- *
10-11-28-18W4	2830	937	820	702	848	614	--	-- *
07-13-28-18W4	2888	1128	1038	819	858	710	802	-- *

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-23-28-18W4	3071	1248	1130	1030	857	824	557	-- *
10-33-28-18W4	3213	1434	1280	1198	1126	980	810	783
10-21-28-17W4	2908	1189	1040	950	890	800	--	-- *
11-23-28-17W4	3027	1270	1184	1080	1008	824	738	814
08-28-28-17W4	2884	1248	1028	858	801	728	850	850
07-32-28-17W4	3084	1338	1280	1188	1110	848	658	758
11-17-28-18W4	2841	1028	884	807	734	858	--	-- *
11-18-28-18W4	2707	1088	970	900	830	874	--	-- *
15-21-28-18W4	2888	1088	928	848	772	--	--	-- *
07-28-28-18W4	2738	1128	928	841	785	--	--	-- *
07-20-28-18W4	2888	1038	878	780	724	--	--	-- *
11-23-28-18W4	3053	1133	1041	937	880	--	--	-- *
10-24-28-18W4	2712	1177	981	907	840	--	--	-- *
10-13-28-20W4	2748	1228	1080	1018	949	777	--	-- *
10-15-28-20W4	2728	1280	1080	1011	958	800	578	520
07-17-28-20W4	2748	1350	1150	1070	1017	848	717	787
11-16-28-20W4	2861	1458	1274	1168	1128	861	850E	510
08-13-28-21W4	2774	1288	1168	1108	1088	808	-- E	540
08-14-28-21W4	3018	1481	1333	1150	1100	857	-- E	ND
10-14-28-21W4	3010	1427	1220	1148	1089	988	-- E	680

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
08-17-28-21W4	2805	1820	1397	1288	1250	1120	1021E	1082
07-18-28-21W4	2980	1714	1505	1401	1382	1231	1140E	1183
07-21-28-21W4	2617	1482	1383	1180	1150	1010	807E	830
11-23-28-21W4	2623	1522	1318	1218	1168	1043	E	878
11-14-28-22W4	2924	1838	1474	1400	1388	1310	E	1127
10-19-28-22W4	2622	1859	1390	1282	1347	1130	E	1038
11-19-28-22W4	2978	1777	1587	1501	1489	1328	E	1290
13-20-28-22W4	2907	1708	1510	1430	1391	1289	E	1173
11-21-28-22W4	3028	1783	1628	1538	1503	1382	E	1288
10-13-28-23W4	2861	1751	1527	1438	1408	1270	E	1183
11-15-28-23W4	3053	1838	1728	1644	1588	1470	E	1410
10-17-28-23W4	3028	1890	1721	1690	1598	1478	E	1428
10-13-28-24W4	3043	2039	1833	1789	1716	1684	E	1513
08-18-28-24W4	3083	2087	1848	1785	1705	1610	E	1583
11-20-28-24W4	3045	2088	1888	1813	1787	1640	E	1588
08-13-28-25W4	2983	2080	1848	1783	1788	1604	E	1557
11-14-28-25W4	3044	2180	1933	1878	1833	1680	E	1604
11-17-28-25W4	3080	2448	2227	2180	2188	2014	E	1878
04-24-28-25W4	3030	2284	2088	2008	1857	1838	E	1781
10-15-28-27W4	3288	2888	2677	2841	2860	2450	E	2378

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-28-28-27W4	3138	2612	2376	2338	2268	2131	E	2027
06-27-28-27W4	3168	2706	2466	2400	2360	2160	E	2138
06-28-28-27W4	3177	2773	2508	2478	2398	2284	E	2217
08-26-28-28W4	3266	2860	2722	2707	2637	2528	E	2468
11-29-28-28W4	3360	3160	2880	2848	2660	2763	E	2750
06-31-28-28W4	3370	3200	3084	2984	2840	2768	E	2720
07-32-28-28W4	3738	3724	3497	3440	3363	3248	E	3214
11-33-28-28W4	3800	3570	3344	3287	3230	3080	E	3080
11-26-28-28W4	3488	3370	3180	3120	3078	2980	E	2974
05-14-28-01W5	3828	3710	3478	3428	3380	3237E	E	3267
01-15-28-01W5	3585	3700	3480	3418	3374	3180E	E	3263
11-17-28-01W5	3763	3870	3769	3708	3684	3668E	E	3574
06-18-28-01W5	3777	3880	3850	3784	3727	E	E	3683
16-15-28-02W5	3878	4263	4088	3872	3834	3780E	E	3908
10-16-28-02W5	4008	4604	4314	4287	4227	4180E	E	4204
01-20-28-02W5	3833	4240	4344	4142	4088	4023E	E	ND
10-06-28-02W5	4124	4838	4828	4767	4768	E	E	4747
11-33-28-03W5	3850	4612	4828	4809	4688	-- E	E	ND
11-30-28-16W4	3110	1388	1182	1080	1010	880	603	683
07-12-28-16W4	3038	1318	1128	1028	948	800	722	630

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-14-28-16W4	3133	1385	1230	1121	1038	891	817	728
10-16-28-16W4	3216	1480	1380	1262	1170	1030	933	770
11-28-28-16W4	3381	1628	1527	1448	1380	1220	1130	1028
04-08-28-17W4	2851	1148	1010	940	848	730	*ND	533
06-11-28-17W4	3421	1668	1550	1473	1378	1280	1180	1063
06-22-28-17W4	3361	1680	1528	1461	1348	1240	ND	1033
07-13-28-18W4	3000	1278	1208	1138	1018	910	ND	728
02-18-28-18W4	2793	1170	1068	974	915	773	ND	690
07-14-28-18W4	2742	1180	1034	940	890	741	ND	-- *
06-18-28-18W4	2883	1180	1030	950	891	748	ND	-- *
10-23-28-18W4	2717	1100	977	890	838	690	ND	-- *
11-18-28-20W4	2821	1142	1048	950	924	776	ND	710
16-26-28-20W4	2887	1188	1030	958	918	768	ND	700
10-28-28-20W4	2841	1120	1028	980	918	780	ND	697
10-18-28-21W4	2883	1331	1170	1128	1068	898	E	838
10-20-28-21W4	2708	1373	1190	1110	1084	918	E	888
10-14-28-22W4	2712	1430	1287	1218	1157	1000	E	933
02-17-28-22W4	2489	1280	1130	1083	1031	880	E	830
10-18-28-22W4	2800	1340	1165	1080	1056	920	E	880
08-12-28-22W4	2778	1615	1421	1380	1388	1229	E	1170

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
05-14-28-23W4	2675	1484	1378	1320	1271	1137	E	1070
07-15-28-23W4	2687	1460	1306	1250	1178	1084	E	1010
07-17-28-23W4	2753	1690	1480	1390	1355	1280	E	1206
07-12-28-24W4	2783	1700	1548	1483	1427	1310	E	1286
08-14-28-24W4	2778	1700	1550	1463	1430	1318	E	1243
13-17-28-24W4	2873	1848	1734	1670	1605	1502	E	1448
09-12-28-25W4	2857	2005	1880	1812	1184	1855	E	1818
10-18-28-25W4	2884	2239	2018	1950	1877	1800	E	1708
10-21-28-25W4	3034	2192	1993	1902	1872	1788	E	1727
09-25-28-26W4	3024	2225	2060	2038	1965	1898	E	1821
14-30-28-26W4	3171	2600	2386	2390	2240	2180	E	2115
07-36-28-26W4	2982	2210	2066	2028	1948	1848	E	1818
05-28-28-27W4	3180	2718	2950	2630	2398	2318	E	2273
05-35-28-27W4	3206	2990	2480	2447	2408	2284	E	2230
07-33-28-28W4	3260	3040	2882	2780	2727	2680	E	2643
08-35-28-28W4	3280	2952	2780	2700	2844	2527	E	2513
06-12-28-29W4	3390	3320	3180	3080	3029	2940	E	2930
03-14-28-29W4	3431	3407	3228	3190	3110	3018	E	3010
05-23-28-29W4	3408	3370	3182	3110	3082	2978	E	2942
02-34-28-29W4	3364	3410	3207	3130	3080	2984	E	2978

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-13-28-01W5	3427	3380	3285	3180	3140	3057	E	3053
07-14-28-01W5	3481	3530	3370	3280	3240	3139	E	3130
07-18-28-01W5	3605	3883	3512	3443	3402	3300	E	3294
07-21-28-01W5	3827	3780	3672	3510	3450	E	E	3340
06-30-28-01W5	3580	3775	3810	3820	3487	E	E	3380
11-31-28-01W5	3585	3794	3840	3654	3510	E	E	3248
10-13-28-02W5	3780	4088	3870	3784	3740	E	E	3644
10-15-28-02W5	3771	4180	3870	3876	3634	E	E	3600
07-18-28-02W5	3795	4281	4048	3880	3810	E	E	3880
03-18-28-02W5	3723	4300	4083	4004	3845	E	E	ND
15-12-28-03W5	3820	4200	4010	3820	3875	E	E	ND
08-13-28-03W5	3823	4210	4023	3930	3881	E	E	ND
10-15-28-03W5	3824	4519	4370	4285	4220	E	E	ND
10-15-28-04W5	4005	5085	4840	4683	4637	E	E	ND
11-13-30-13W4	2891	685	621	560	526	--	--	*
05-23-30-14W4	2583	663	607	597	523	--	--	*
10-27-30-15W4	2780	1040	870	784	720	--	--	*
07-26-30-15W4	2668	855	737	641	582	--	--	*
10-23-30-16W4	2804	1166	1012	946	862	730	629	517
11-23-30-16W4	2832	1185	1041	980	ND	770	680	*

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-24-30-16W4	2882	1129	976	887	827	690	593	*
10-27-30-16W4	2861	1133	970	888	842	700	579	*
08-28-30-16W4	3032	1369	1190	1113	1066	915	772	698
11-12-30-17W4	3538	1827	1719	1636	1590	1437	1287	1235
07-14-30-17W4	3373	1788	1578	1503	1455	1300	1160	1095
14-28-30-17W4	3041	1427	1294	1173	1124	985	835	770
08-31-30-17W4	2949	1280	1172	1080	1031	913	798	695
04-11-30-18W4	2885	1292	1100	1006	945	810	680	610
10-12-30-18W4	2983	1405	1210	1118	1058	919	771	737
10-15-30-18W4	2901	1354	1152	1060	995	869	712	649
07-17-30-18W4	2821	1280	1085	994	942	810	669	608
10-18-30-18W4	2885	1321	1147	1088	1011	870	733	700
08-18-30-18W4	2884	1168	1004	940	889	759	601	560
11-17-30-18W4	2875	1177	1005	939	880	735	--	*
11-18-30-18W4	2831	1150	984	900	839	705	--	*
07-22-30-19W4	2797	1340	1120	1050	990	857	708	680
07-23-30-19W4	2770	1311	1080	1013	959	816	681	*
10-24-30-19W4	2762	1244	1058	994	934	791	635	*
08-16-30-20W4	2743	1307	1140	1074	1023	875	730	705
04-17-30-20W4	2721	1323	1136	1087	1019	888	725	*

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-22-30-20W4	2714	1214	1074	989	958	814	680	650
04-23-30-20W4	2707	1250	1050	968	926	803	683	*
02-24-30-20W4	2688	1120	901	860	769	659	--	*
11-18-30-21W4	2872	1528	1227	1169	1121	962	850	835
08-20-30-21W4	2862	1420	1215	1150	1120	957	850	840
08-22-30-21W4	2872	1310	1101	1040	999	866	747	708
08-24-30-21W4	2700	1328	1124	1060	1010	863	722	ND
07-19-30-22W4	2703	1540	1358	1301	1264	1128	E	1076
11-21-30-22W4	2685	1448	1290	1227	1181	1036	E	995
11-22-30-22W4	2639	1406	1235	1173	1131	968	E	944
08-23-30-22W4	2684	1428	1253	1198	1151	991	E	980
08-24-30-22W4	2686	1460	1259	1198	1152	1000	E	935
10-14-30-23W4	2815	1507	1330	1270	1229	1098	E	1040
14-19-30-23W4	2823	1734	1610	1580	1530	1400	E	1345
08-20-30-23W4	2639	1787	1606	1541	1515	1342	E	1285
11-19-30-24W4	3055	2150	1981	1931	[illegible]	1760	E	1720
08-21-30-24W4	3012	2104	1925	1880	1838	1697	E	1660
10-22-30-24W4	2883	2050	1845	1799	1770	1620	E	1570
10-23-30-24W4	2808	1943	1734	1690	1658	1498	E	1450
08-28-30-24W4	2894	1916	1874	1838	1808	1460	E	1410

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
08-22-30-28W4	2839	2220	1970	1934	1904	1759	E	1726
06-24-30-28W4	2926	2102	1910	1870	1845	1685	E	1650
12-26-30-28W4	2956	2157	1976	1949	1817	1763	E	1726
11-03-30-28W4	3109	2587	2308	ND	2259	2083	E	2068
04-11-30-28W4	2861	2330	2088	ND	2024	1848	E	1817
10-19-30-27W4	3181	2863	2831	--	2579	2376	E	2336
02-20-30-27W4	3181	2718	2562	--	2528	2342	E	2327
10-21-30-27W4	3080	2620	2497	--	2442	2260	E	2233
10-25-30-27W4	3047	2487	2330	--	2301	2127	E	2090
10-11-30-28W4	3268	2932	2788	--	2741	2529	E	2849
13-12-30-28W4	3288	2824	2806	--	2747	2522E	E	2634
11-14-30-28W4	3289	3024	2827	--	2760	2584E	E	2640
11-15-30-28W4	3274	2980	2862	--	2770	2598E	E	2680
10-18-30-28W4	3302	3007	2915	--	2851	2652E	E	2728
08-18-30-28W4	3331	3184	3057	--	2988	2790E	E	2884
11-14-30-29W4	3289	3234	3098	--	3019	2630E	E	2883
02-14-30-01W5	3356	3414	3284	--	3171	2957E	E	3040
08-18-30-01W5	3541	3820	3818	--	3526	3309E	E	3394
10-22-30-01W5	3369	3553	3363	--	3265	3087E	E	3133
14-18-30-02W5	3857	4150	3914	--	3818	3590E	E	3700

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-28-30-02W5	3840	3905	3700	--	3810	3362E	E	3474
10-30-30-02W5	3582	4223	4000	--	3895	3891E	E	3775
10-01-30-03W5	--	4179	3990	--	3898	3585E	E	3748
08-03-30-03W5	--	4320	4149	--	4050	3810E	E	3900
15-08-30-03W5	3886	4500	4310	--	4208	4000E	E	4087
07-12-30-04W5	3752	4725	4525	--	4415	4200E	E	4332
08-05-31-15W4	2852	1040	880	830	785	852	--	*
01-14-31-15W4	2884	850	780	665	600	470	--	*
07-17-31-15W4	2752	900	836	739	690	558	--	*
10-32-31-15W4	2783	988	876	761	730	590	480	385
08-12-31-16W4	2748	895	840	788	700	575	470	375
08-08-31-17W4	2832	1247	1170	1088	1048	900	802	878
08-12-31-17W4	2888	1250	1178	1088	1048	890	787	709
08-28-31-17W4	2867	1328	1188	1100	1080	901	835	685
08-29-31-17W4	2880	1310	1190	1110	1088	915	838	890
07-04-31-18W4	2841	1282	1136	1050	1007	888	705	840
08-16-31-18W4	2901	1297	1170	1097	1049	910	750	704
04-29-31-18W4	2847	1285	1104	1028	988	856	700	690
06-21-31-19W4	2785	1250	1128	1049	1010	871	779	718
10-29-31-19W4	2784	1235	1135	1084	1032	900	780	750

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-15-31-20W4	2712	1270	1108	1013	1000	855	734	700
11-18-31-20W4	2842	1410	1281	1210	1160	1010	E	950
10-33-31-20W4	2750	1300	1192	1098	1082	914	E	884
11-14-31-21W4	2688	1382	1177	1108	1081	810	E	850
10-15-31-21W4	2850	1258	1154	1067	1053	907	E	840
08-18-31-21W4	2775	1532	1360	1267	1284	1128	E	1035
08-20-31-21W4	2743	1408	1307	1230	1203	1050	E	982
10-15-31-22W4	2748	1570	1397	1327	1303	1153	E	1050
07-17-31-22W4	2688	1585	1392	ND	1328	1180	E	1110
07-19-31-22W4	2782	1640	1470	1424	1414	1230	E	1170
07-20-31-22W4	2694	1575	1400	ND	1340	1180	E	1121
10-13-31-23W4	2837	1650	1580	1510	1506	1340	E	1272
03-18-31-23W4	2940	1888	1730	1688	1620	1520	E	1480
11-18-31-23W4	2981	1980	1809	1732	1690	1580	E	1525
11-30-31-23W4	2952	2040	1818	1732	1681	1588	E	1516
14-09-31-24W4	2938	2082	1852	1782	1785	1639	E	1595
08-10-31-24W4	2878	2050	1880	1817	1772	1657	E	1615
15-18-31-24W4	2854	2388	2160	2115	2060	1872	E	1943
14-34-31-24W4	2819	1805	1707	1650	1606	1498	E	1458
08-12-31-25W4	3045	2245	2040	1981	1922	1834	E	1750

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-18-31-25W4	3081	2387	2180	2130	2090	2008	E	1840
10-18-31-26W4	3013	2330	2128	2090	2048	1950	E	1900
16-25-31-26W4	3052	2180	2020	1976	1947	1848	E	1830
07-30-31-26W4	3178	2686	2483	2439	2410	2213E	E	2302
10-03-31-27W4	3080	2581	2450	2394	2346	E	E	2281
02-18-31-27W4	3150	2870	2682	2610	2531	E	E	2470
10-23-31-27W4	3088	2610	2452	2403	2380	E	E	2287
11-28-31-27W4	3102	2630	2486	2423	2370	E	E	2270
10-18-31-28W4	3186	3100	2885	ND	2800	E	E	2749
11-22-31-28W4	3204	3111	2956	ND	2875	E	E	2800
11-11-31-01W5	3318	3450	3244	3180	3120	E	E	2890
10-20-31-01W5	3375	3579	3400	3345	3287	E	E	3190
10-32-31-01W5	3370	3590	3412	3381	ND	E	E	3218
07-34-31-01W5	3383	3540	3302	ND	3217	E	E	3092
11-22-31-02W5	3464	3803	3678	3600	3550	E	E	3524
10-24-31-02W5	3417	3704	3480	3362	3304	E	E	3258
05-29-31-02W5	3807	4052	3814	3728	3680	E	E	3589
10-25-31-03W5	3598	4260	3988	3922	3817	E	E	3800
10-27-31-03W5	3387	4083	3820	ND	3798	E	E	3654
09-29-31-03W5	3684	4350	4170	ND	4058	E	E	3910

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-12-31-04W5	3834	4620	4390	4326	4287	E	E	4135
16-13-31-04W5	3835	4610	4405	4332	4272	E	E	4130
14-14-31-04W5	3741	4716	4506	4469	4380	E	E	4300
13-16-31-04W5	3672	4730	4570	4520	4480	E	E	4385
08-30-31-04W5	3802	4810	4729	4580	4598	E	E	4516
10-08-32-15W4	2681	630	760	880	631	480	*	*
10-32-32-15W4	2701	930	780	894	840	503	*	*
12-32-32-16W4	2716	[illegible]	882	805	781	613	*	*
08-22-32-17W4	2757	1100	960	890	850	708	570	500
07-23-32-17W4	2748	1116	1008	884	830	689	*	*
08-34-32-17W4	2783	1090	1000	836	880	780	620	543
11-17-32-18W4	2867	1310	1166	1080	1080	923	770	720
08-30-32-18W4	2850	1330	1186	1104	1077	940	778	720
10-13-32-19W4	2827	1290	1184	1078	1050	922	765	710
11-15-32-19W4	2850	1360	1215	1127	1104	930	780	757
16-20-32-19W4	2881	1500	1282	1188	1180	1043	E	967
12-10-32-20W4	2701	1306	1148	1076	1045	880	E	810
11-15-32-20W4	2726	1320	1165	1116	1080	922	E	856
11-19-32-20W4	2764	1470	1260	1184	1130	1050	E	984
10-13-32-21W4	2764	1488	1269	1192	1182	1050	E	982

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-18-32-21W4	2738	1480	1300	1230	1200	1080	E	1002
10-18-32-21W4	2490	1310	1120	1043	1020	880	E	817
10-13-32-22W4	2772	1605	1402	1344	1304	1155	E	1102
11-20-32-22W4	2771	1720	1510	1449	1420	1278	E	1217
11-23-32-23W4	2823	1740	1582	1562	1530	1372	E	1324
07-27-32-23W4	2782	1790	1566	1498	1465	1330	E	1280
12-18-32-24W4	2862	2050	1841	1780	1750	1620	E	1580
11-27-32-24W4	2681	2010	1800	1740	1720	1660	E	1535
06-28-32-24W4	2670	2005	1816	1750	1727	1581	E	1550
05-25-32-25W4	2886	2100	1880	1812	1788	1670	E	1607
08-24-32-25W4	2937	2145	1950	--	1850	1769	E	1720
13-14-32-26W4	3036	2446	2210	2137	2080	2020	E	1981
15-19-32-26W4	3024	2500	2297	2216	2190	2088	E	2070
10-13-32-27W4	3102	2600	2400	2320	2264	2210	E	2200
07-20-32-27W4	3188	2816	2643	2576	2513	E	E	2437
07-28-32-28W4	3209	3042	2800	2823	2760	2680	E	2643
07-12-32-01W5	3289	3254	3080	3007	2940	E	E	2872
11-17-32-01W5	3403	3850	3410	--	3280	E	E	3238
03-16-32-01W5	3382	3540	3420	3348	3314	E	E	3200
10-15-32-02W5	3385	3754	3810	3815	3470	E	E	3440

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
11-14-32-03W5	3487	4148	3950	3903	3854	E	E	3798
08-15-32-03W5	3432	4148	3940	3880	3838	E	E	3750
08-18-32-03W5	3510	4357	4150	4078	4020	E	E	3948
15-19-32-04W5	3738	4898	4830	4873	4820	E	E	4577
05-20-32-04W5	3888	4822	4734	4810	4570	E	E	4514
03-25-32-04W5	3610	4420	4254	4194	4150	E	E	4168
07-26-33-18W4	2803	883	878	803	730	610	487	*
03-05-33-18W4	2782	1040	932	857	782	670	530	478
08-30-33-18W4	2874	985	835	758	710	590	428	380
07-28-33-17W4	2708	1045	ND	855	793	680	ND	470
07-31-33-17W4	2890	1050	915	850	788	690	545	492
07-08-33-18W4	2860	1280	1168	1118	1085	939	800	750
07-01-33-19W4	2871	1278	1200	1118	1088	950	800	722
08-07-33-18W4	2807	1338	1248	1152	ND	1003	900	834
08-10-33-20W4	2705	1285	1188	1121	1090	942	830	858
07-14-33-20W4	2748	1285	1182	1123	1106	958	850	871
08-28-33-20W4	2784	1280	1220	1153	1132	983	E	908
07-14-33-21W4	2786	1470	1370	1278	1262	1124	E	1090
11-16-33-21W4	2835	1580	1427	1354	1331	1188	E	1150
07-32-34-17W4	2788	1070	978	944	873	145	745	590

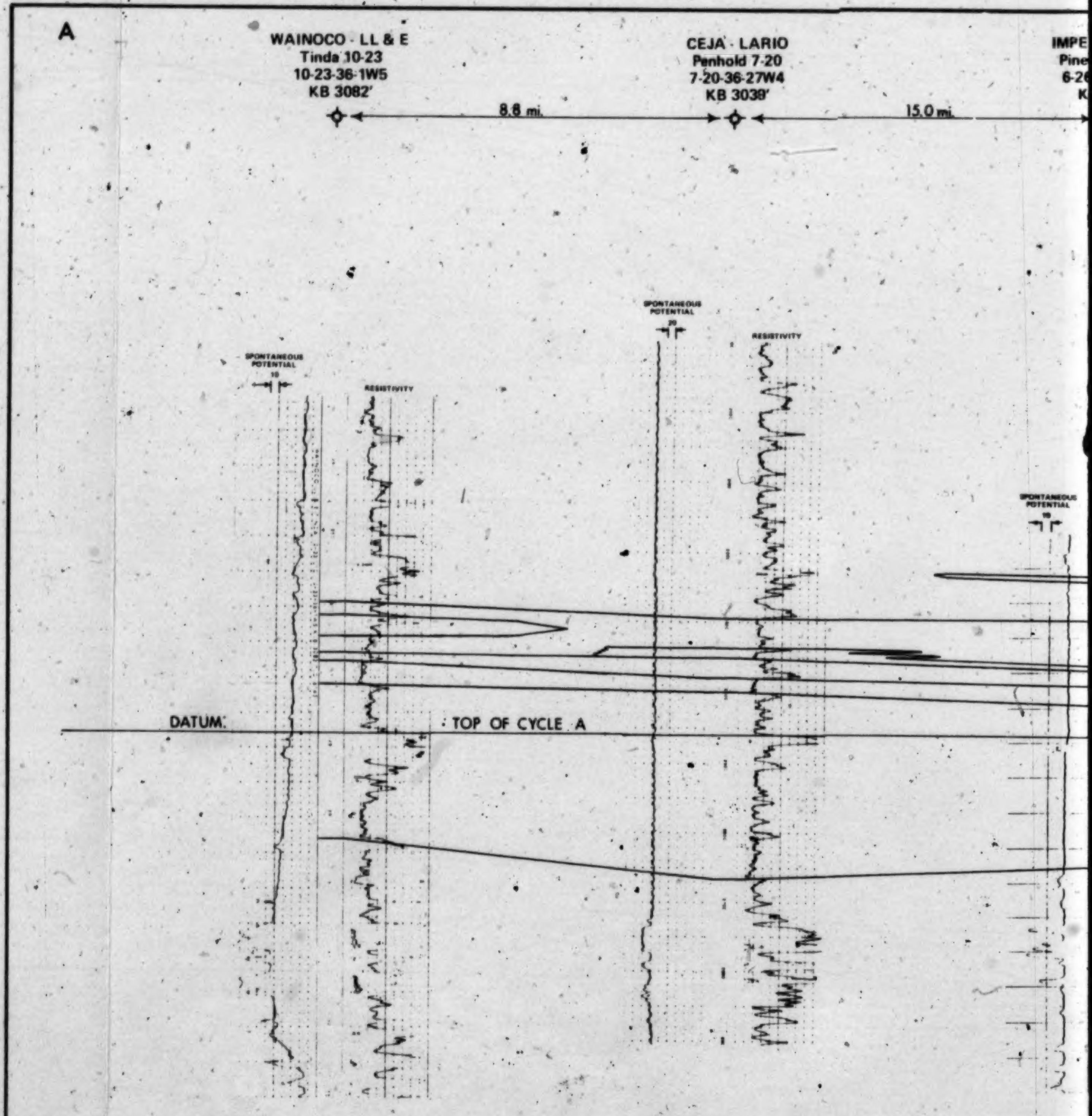
Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
03-17-34-18W4	2778	1202	1059	1018	990	820	722	*
08-28-34-19W4	2808	1280	1158	1038	1020	879	ND	800
11-12-34-20W4	2868	1440	1300	1241	1211	1070	950	1020
11-28-35-14W4	2858	750	700	610	550	380	*	*
10-32-35-15W4	2721	875	810	705	640	500	*	*
06-22-35-16W4	2854	1072	1000	908	808	690	*	*
11-18-35-17W4	2748	1042	918	850	727	657	578	512
11-20-35-17W4	2801	1110	980	927	850	735	628	578
11-28-35-18W4	2724	1075	1000	940	874	730	580	525
07-27-35-19W4	2784	1280	1140	1074	972	843	610	615
07-28-36-12W4	2688	730	598	563	488	*	*	*
08-24-36-13W4	2718	778	658	597	520	380	*	*
08-25-36-13W4	2716	767	642	568	510	483	383	*
10-20-36-14W4	2881	750	640	610	504	408	*	*
10-25-36-15W4	2811	870	849	813	705	600	505	431
10-20-36-16W4	2811	1022	892	--	788	643	564	470
08-22-36-17W4	2730	1010	848	--	729	600	--	545
08-21-36-17W4	2718	1000	870	--	740	628	517	480
10-19-36-17W4	2732	1018	893	780	770	687	550	510
08-24-36-18W4	2718	1080	910	--	780	687	*	*

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
13-15-38-18W4	2745	1180	1008	--	--	787	--	710
10-21-38-18W4	2758	1205	1026	--	1001	824	703	682
10-22-38-19W4	2887	1488	1288	--	--	1058	988	934
04-19-38-19W4	2888	1482	1282	--	--	1087	980	935
15-23-38-20W4	2788	1380	1174	--	1020	828	--	880
01-32-38-20W4	2768	1452	1238	--	--	1000	--	970
15-31-38-20W4	2828	1542	1318	1280	1190	1080	E	1080
14-35-38-21W4	2919	1703	1480	1440	1336	1278	E	1230
08-33-38-21W4	3037	1883	1658	1608	1530	1454	E	1387
10-16-38-21W4	2914	1780	1524	--	1410	1332	E	1290
06-08-38-21W4	2770	1646	1390	--	1260	1200	E	1148
10-14-38-22W4	2805	1810	1547	1526	1443	1368	E	1334
08-17-38-22W4	2970	1980	1720	1682	1618	1460	E	1400
10-15-38-23W4	2855	1984	1742	--	1650	1570	E	1554
07-20-38-23W4	3092	2108	1930	1905	1833	1760	E	1737
10-25-38-24W4	3051	2120	1940	1912	1830	1750	E	1730
08-22-38-24W4	3100	2280	2080	--	2000	1890	E	1875
08-28-38-25W4	3054	2274	2080	--	2048	1914	E	1880
08-17-38-26W4	3285	2547	2382	--	2250	2180	E	2187
07-13-38-27W4	3179	2630	2488	--	2350	E	E	2280

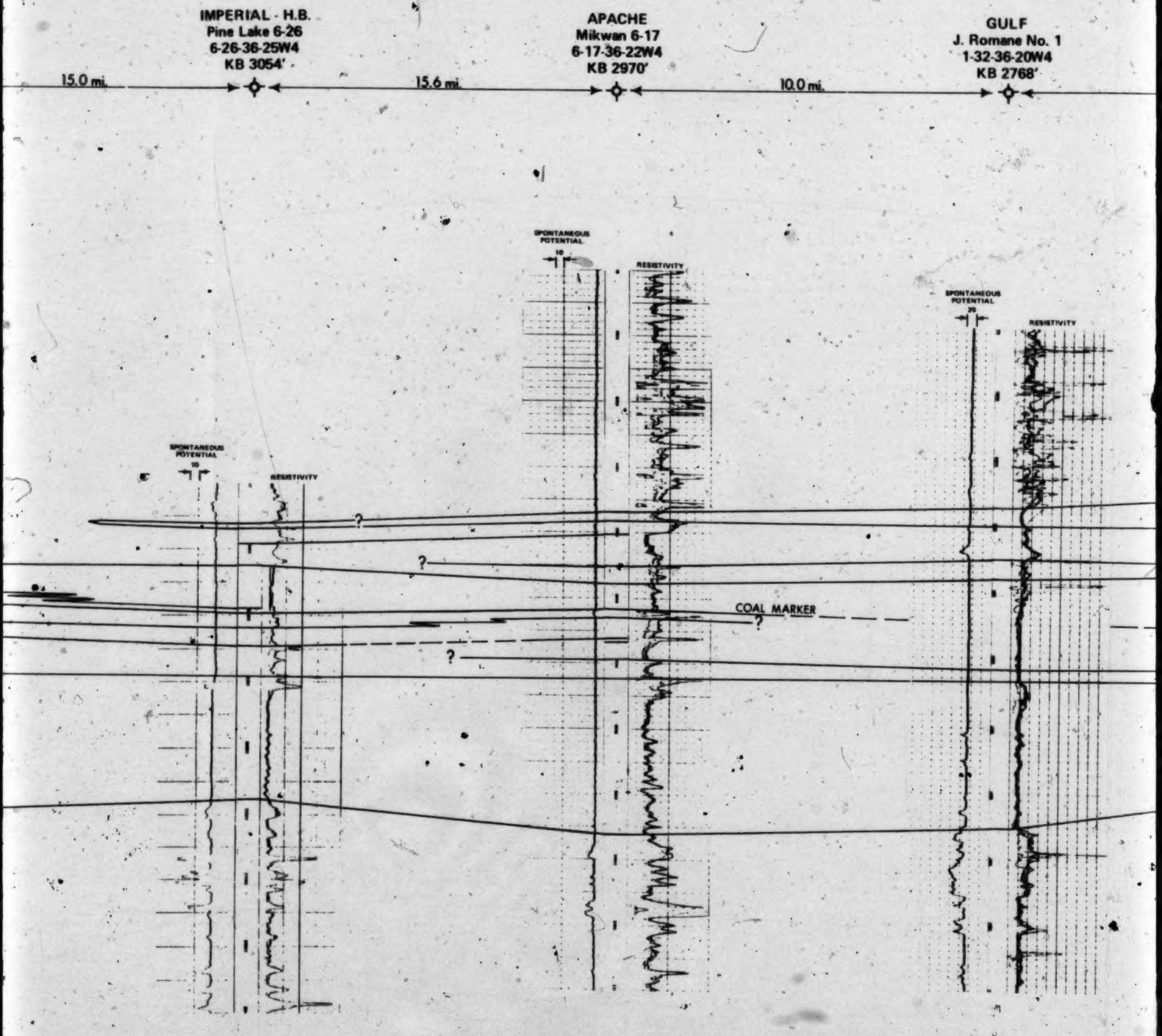
Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
07-20-38-27W4	3039	2655	2458	--	2339	E	E	2283
07-24-38-28W4	2988	2730	2518	--	2388	E	E	2339
08-26-38-28W4	3013	2805	2600	--	2443	E	E	2410
10-23-38-01W5	3082	2930	2780	--	2610	E	E	--
10-28-38-01W5	3021	3050	2885	--	2725	E	E	2734
10-22-38-02W5	2999	3112	2950	--	2800	E	E	2787
11-28-38-02W5	3041	3268	3050	--	2910	E	E	2853
16-12-38-03W5	3125	3475	3270	--	3139	E	E	3123
04-17-38-03W5	3188	3742	3570	--	3416	E	E	3389
10-16-38-03W5	3205	3770	3604	--	3438	E	E	3408
08-24-38-04W5	3230	3800	3627	3608	--	E	E	3438
10-08-38-04W5	3282	4078	3812	3780	3765	E	E	3704
07-13-38-05W5	3303	4211	4032	3914	3849	E	E	3822
04-08-38-05W5	3387	4508	4423	4327	4218	E	E	4190
02-18-38-06W5	3442	4730	4541	4448	4348	E	E	4320
07-08-38-08W5	3920	6148	6018	5915	5816E	E	E	5580
10-21-37-13W4	2784	930	770	712	577	500	*	*
07-28-37-13W4	2788	873	734	678	545	484	*	*
06-07-37-15W4	2704	868	688	585	582	457	*	*
08-10-38-01W5	3720	3867	3590	3480	3449	3290E	E	3331

Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
14-15-28-01W5	3707	3880	3580	3510	3473	E	E	3356
10-22-28-01W5	3587	3750	3485	3445	3398	E	E	3248
10-27-28-01W5	3648	3783	3498	3448	3400	E	E	3300
07-33-28-01W5	2788	3800	3689	3627	3582	E	E	3450
07-25-28-02W5	3919	4231	4025	3979	3930	E	E	3774
16-10-27-02W5	4030	4420	4211	4130	4093	E	E	3994
07-15-27-02W5	3998	4438	4190	4110	4060	E	E	3945
10-22-27-02W5	3965	4400	4164	4117	4039	E	E	3925
06-26-27-02W5	4015	4417	4180	4100	4050	E	E	4010
11-34-27-02W5	3996	4420	4200	4125	4077	E	E	4037
10-03-28-02W5	3950	4385	4180	4051	4053	E	E	4026
10-09-28-02W5	3987	4438	4230	4130	4082	E	E	4064
16-15-28-02W5	3878	4284	4088	3972	3933	E	E	3905
08-22-28-02W5	3868	4284	4094	4000	3950	E	E	3868
08-26-28-02W5	3955	4484	4210	4119	4083	E	E	4038
12-33-28-02W5	3899	4480	4188	4090	4050	E	E	4010
06-10-29-02W5	3845	4308	4070	3970	3934	E	E	3899
10-15-29-02W5	3771	4180	3970	3877	3833	E	E	3800
06-23-29-02W5	3787	4111	3958	3864	3828	E	E	3781
10-27-29-02W5	3714	4065	3911	3819	3780	E	E	3750

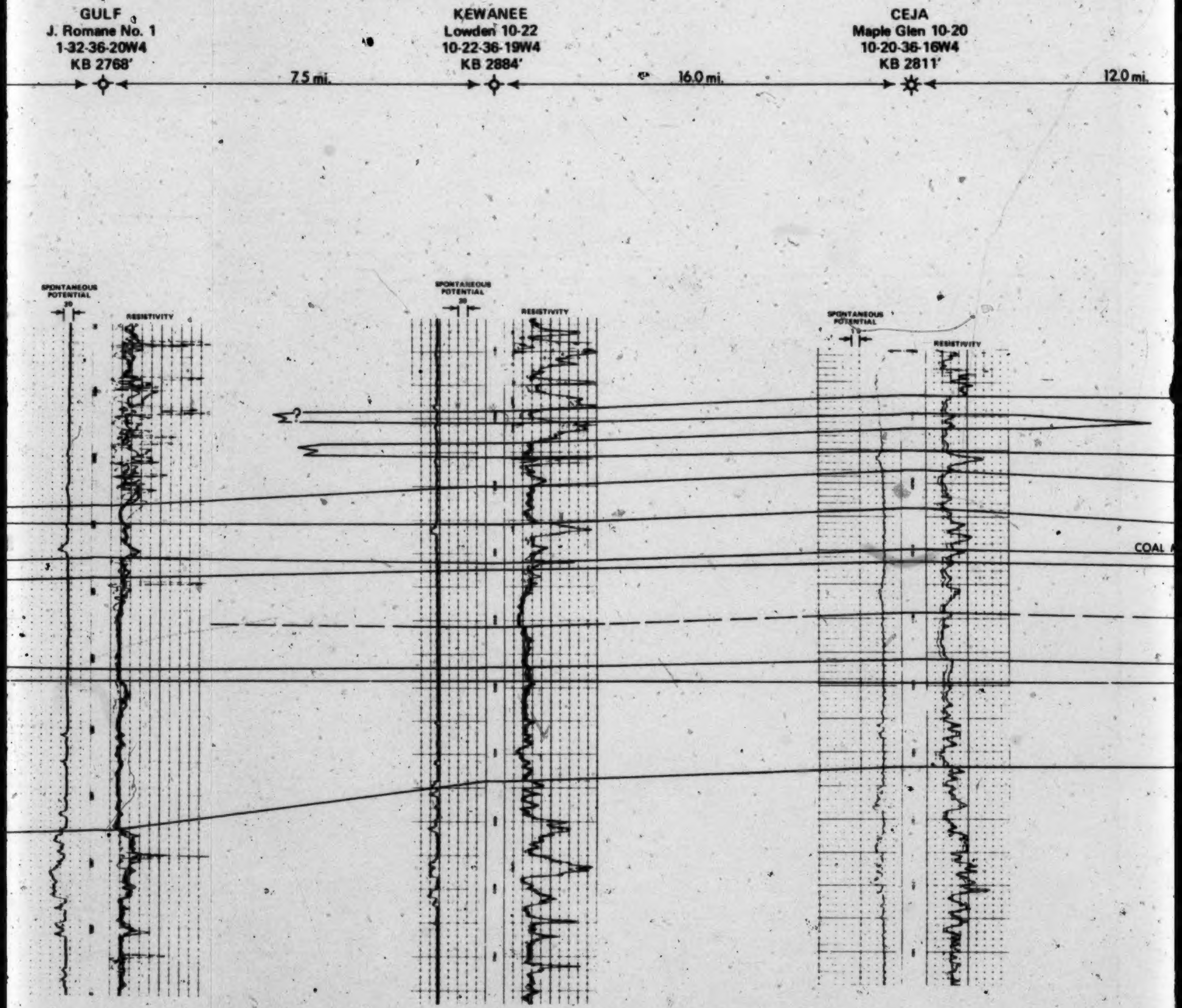
Well Location	Kelly Bushing Elevation	Judith River Formation	Cycle A	Cycle B	Cycle C	Cycle D	Cycle E	Bearpaw Formation
10-33-29-02W5	3847	4080	3885	3804	3767	E	E	3730
10-09-31-02W5	3831	4003	3814	3720	3671	E	E	3651
10-24-31-02W5	3417	3704	3480	3390	3370	E	E	3327
11-22-31-02W5	3484	3803	3676	3600	3550	E	E	3524
08-29-31-02W5	3507	4050	3814	3729	3680	E	E	3640
11-31-31-02W5	3538	4120	3880	3790	3750	E	E	3700
10-10-32-02W5	3381	3760	3560	3470	3430	E	E	3388
10-18-32-02W5	3365	3754	3610	3514	3470	E	E	3440
04-21-32-02W5	3397	3795	3650	3587	3511	E	E	3500
04-29-32-02W5	3470	3883	3775	3680	3648	E	E	3605
04-31-32-02W5	3515	4030	3825	3740	3696	E	E	3662
10-04-33-02W5	3372	3708	3534	3450	3405	E	E	3360
07-11-33-02W5	3315	3622	3450	3363	3327	E	E	3282
11-18-33-02W5	3329	3684	3522	3440	3408	E	E	3349
11-28-33-02W5	3343	3712	3530	3440	3376	E	E	3352
08-32-33-02W5	3243	3650	3474	3376	3333	E	E	3294
10-08-34-02W5	3233	3540	3398	3305	3280	E	E	3225
11-23-34-02W5	3242	3514	3325	3236	3192	E	E	3133
16-32-34-02W5	3119	3518	3280	3180	--	E	E	3112
10-26-35-02W5	3111	3349	3104	3028	--	E	E	2950


A
WAINOCO - LL & E
Tinda 10-23
10-23-36-1W5
KB 3082'
8.8 mi.
CEJA - LARIO
Penhold 7-20
7-20-36-27W4
KB 3039'
15.0 mi.
IMPE
Pine
6-26
K
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
10
DATUM:
TOP OF CYCLE A

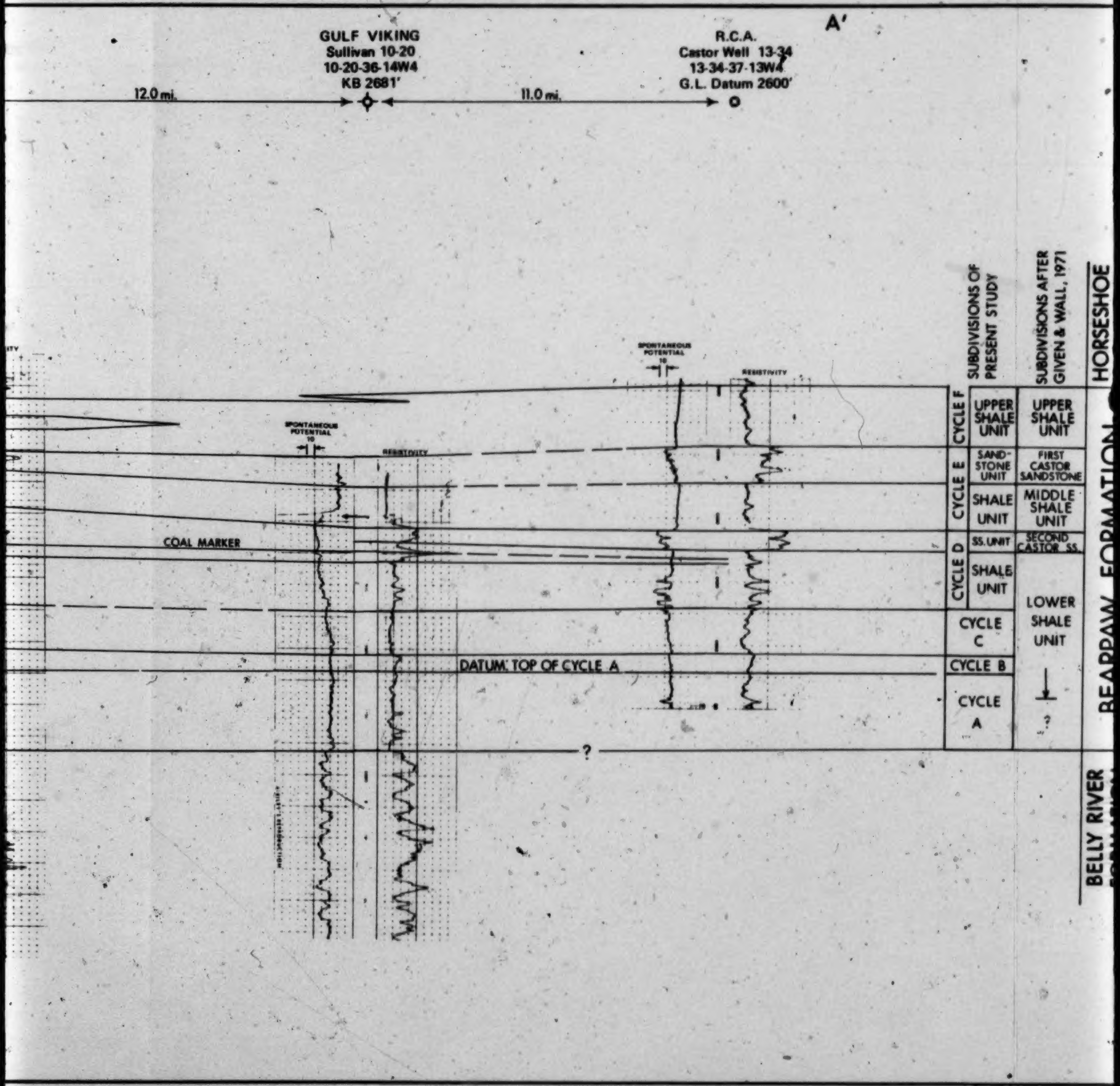
1 OF


IMPERIAL - H.B.
Pine Lake 6-26
6-26-36-25W4
KB 3054'
APACHE
Mikwan 6-17
6-17-36-22W4
KB 2970'
GULF
J. Romane No. 1
1-32-36-20W4
KB 2768'
15.0 mi.
15.6 mi.
10.0 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
?
?
COAL MARKER
?
?

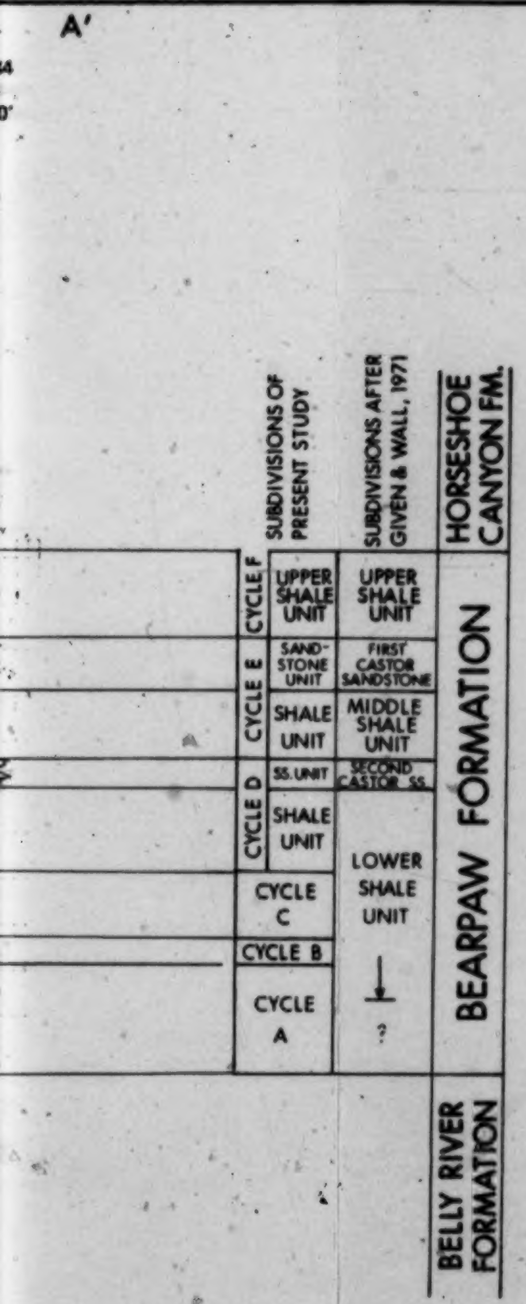
2 OF

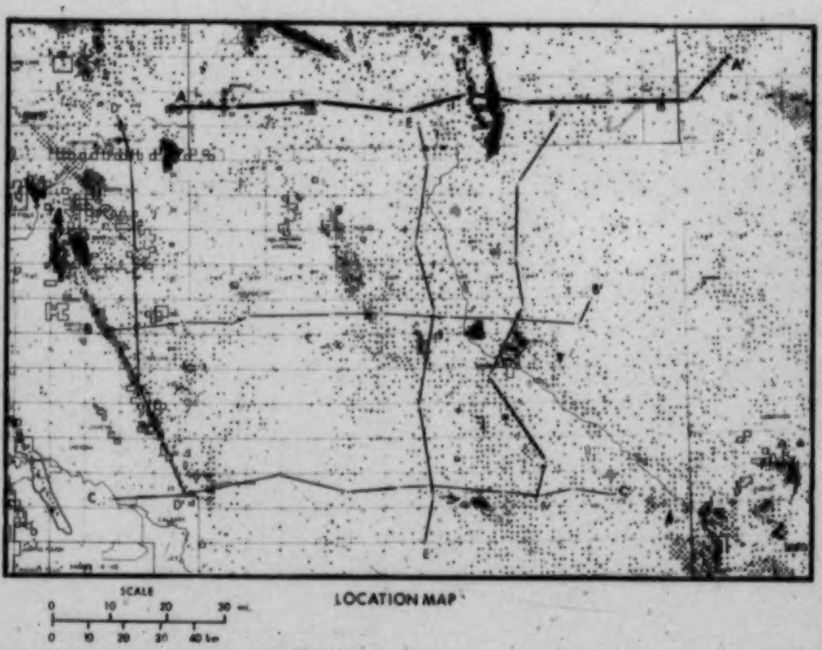

GULF
J. Romane No. 1
1-32-36-20W4
KB 2768'
7.5 mi.
KEWANEE
Lowden 10-22
10-22-36-19W4
KB 2884'
16.0 mi.
CEJA
Maple Glen 10-20
10-20-36-16W4
KB 2811'
12.0 mi.
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
?
COAL

3 OF


A'
GULF VIKING
Sullivan 10-20
10-20-36-14W4
KB 2681'
R.C.A.
Castor Well 13-34
13-34-37-13W4
G.L. Datum 2600'
12.0 mi.
11.0 mi.
SPONTANEOUS POTENTIAL
RESISTIVITY
COAL MARKER
DATUM: TOP OF CYCLE A
?
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
CYCLE F
UPPER SHALE UNIT
UPPER SHALE UNIT
CYCLE E
SAND-STONE UNIT
FIRST CASTOR SANDSTONE
SHALE UNIT
MIDDLE SHALE UNIT
CYCLE D
SS. UNIT
SECOND CASTOR SS.
SHALE UNIT
LOWER SHALE UNIT
CYCLE C
CYCLE B
CYCLE A
?
HORSESHOE
BEARPAW FORMATION
BELLY RIVER

4 OF


A'
34
0'
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
HORSESHOE CANYON FM.
CYCLE F
UPPER SHALE UNIT
UPPER SHALE UNIT
CYCLE E
SAND-STONE UNIT
FIRST CASTOR SANDSTONE
SHALE UNIT
MIDDLE SHALE UNIT
CYCLE D
SS.UNIT
SECOND CASTOR SS
SHALE UNIT
LOWER SHALE UNIT
CYCLE C
CYCLE B
CYCLE A
?
BEARPAW FORMATION
BELLY RIVER FORMATION


A
A'
B
C
C'
D
D'
E
E'
SCALE
0
10
20
30 mi
0
10
20
30
40 km

LOCATION MAP

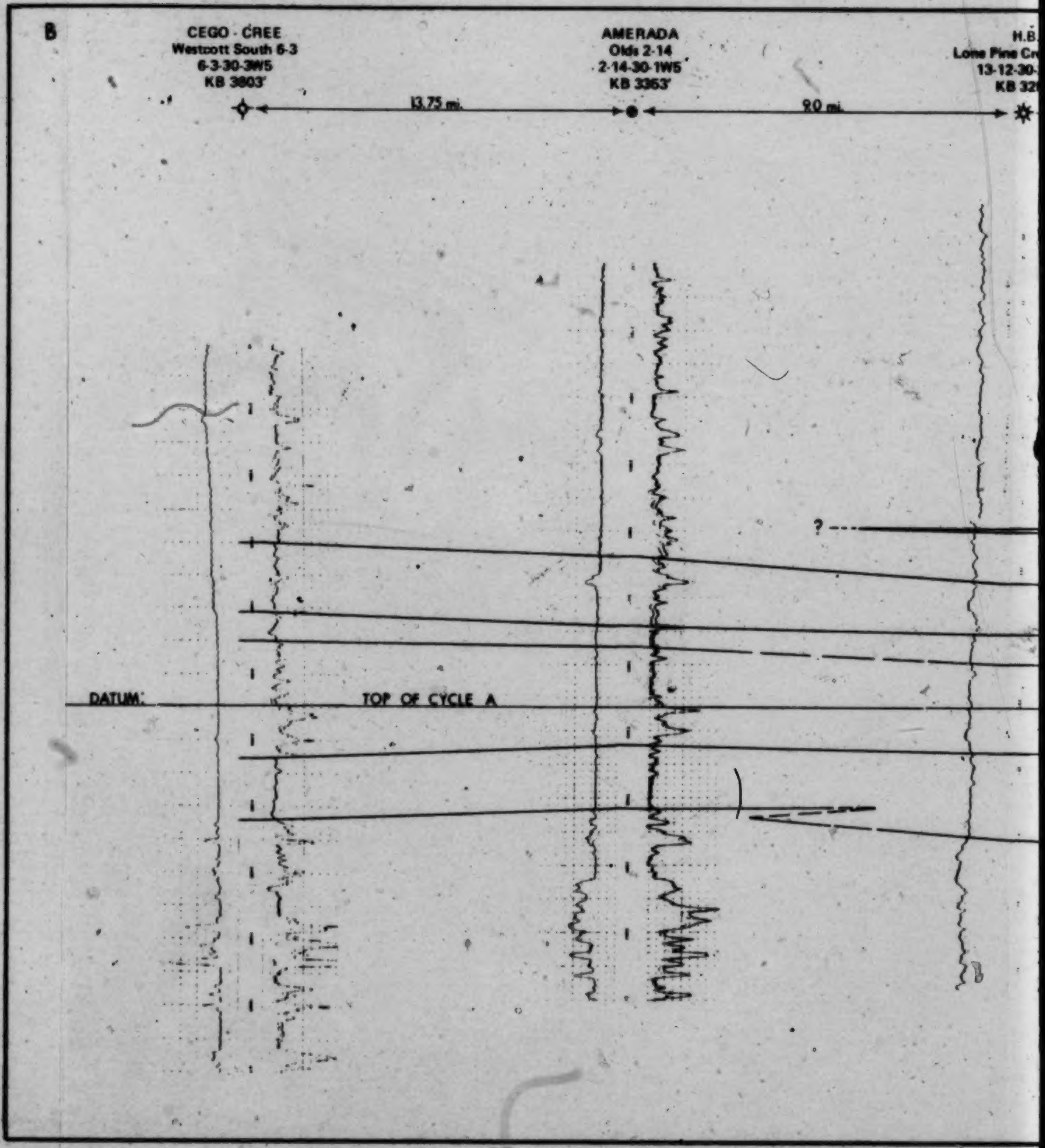
FIGURE 6.

STRATIGRAPHIC CROSS SECTION A-A'

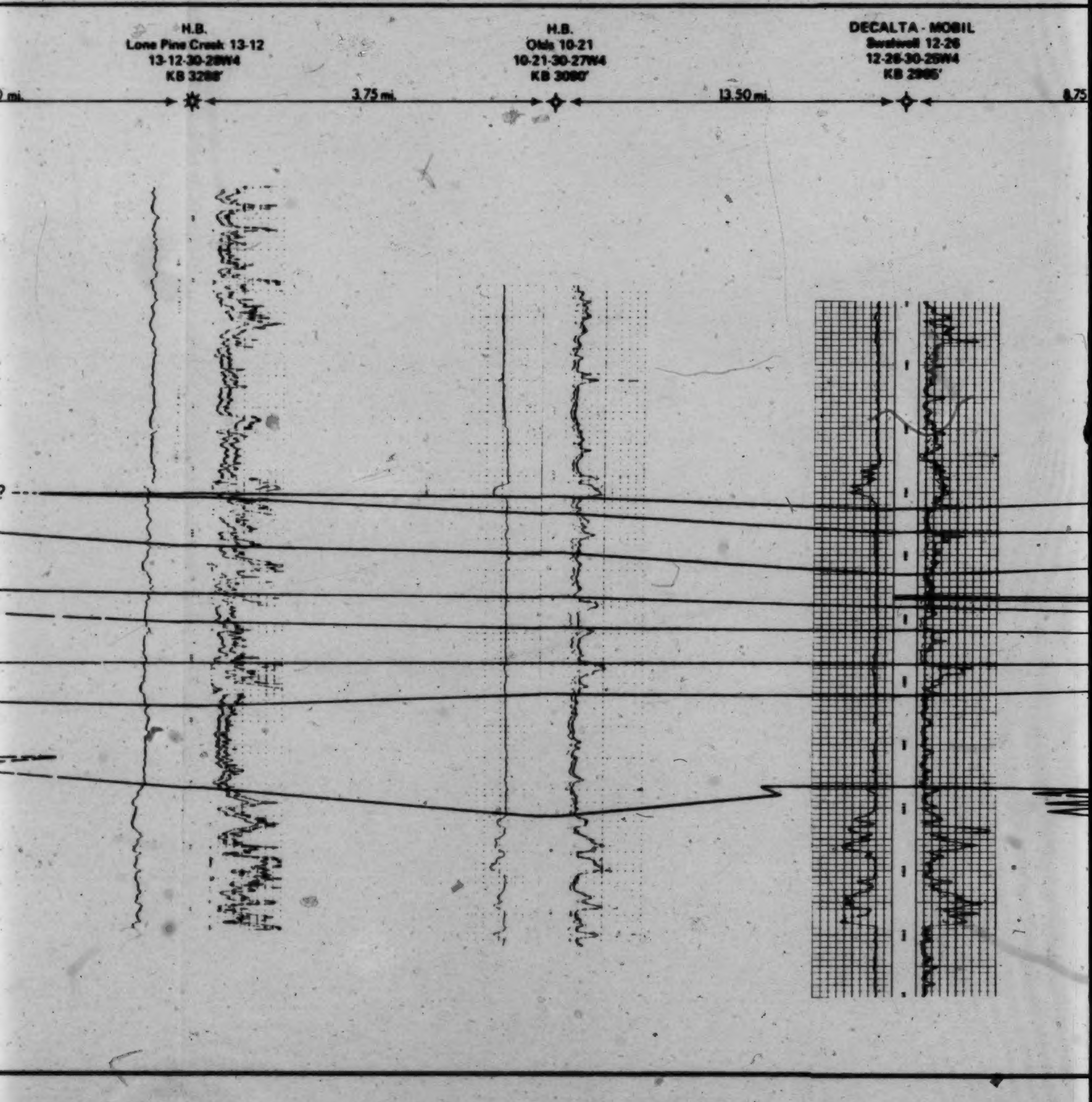
WAINOCO Tinda 10-23 to RCA Castor 13-34

Antoine J.E. Habib
University of Alberta
1980

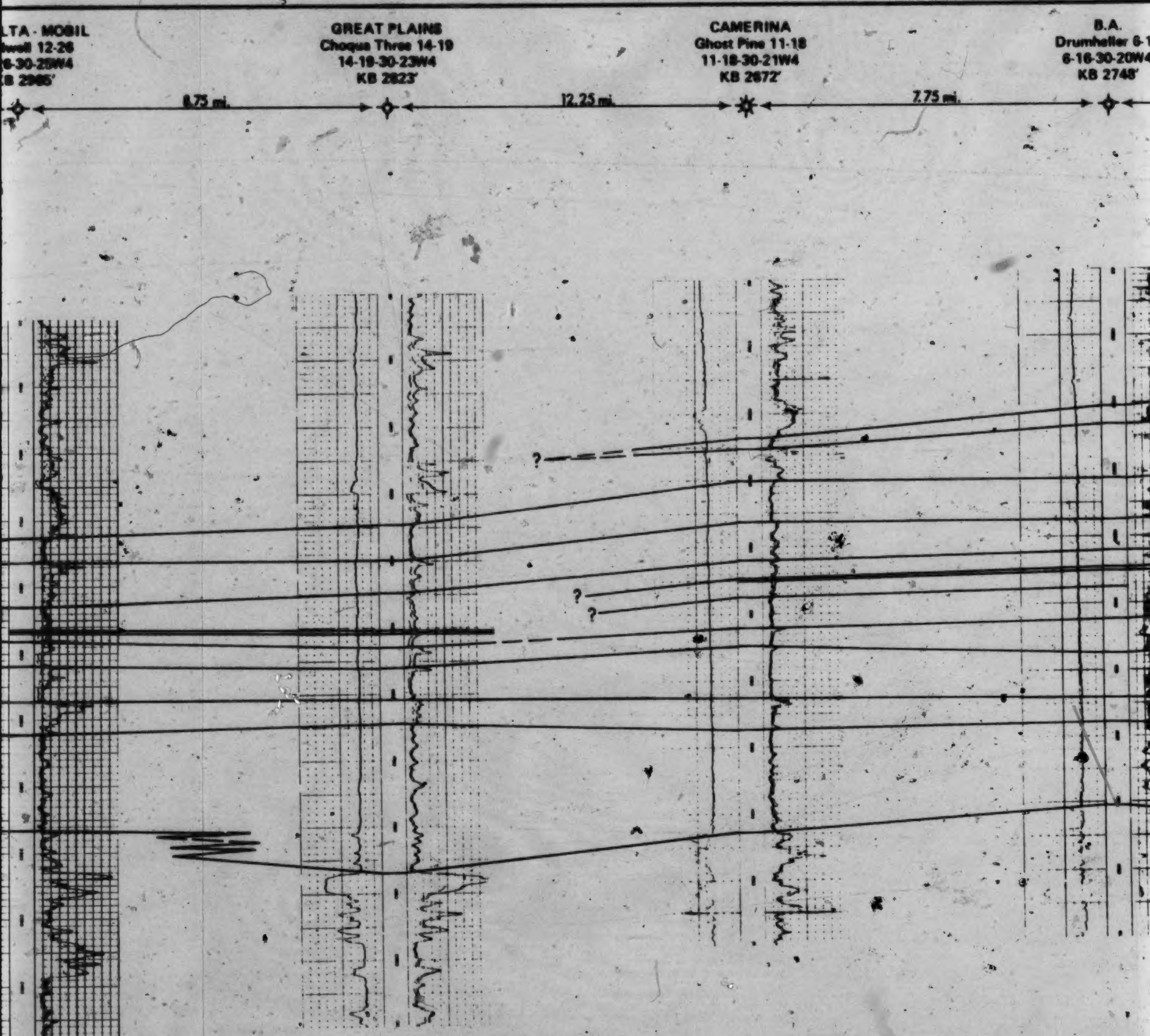
5 OF 5


B
CEGO - CREE
Westcott South 6-3
6-3-30-3W5
KB 3803'
AMERADA
Olds 2-14
2-14-30-1W5
KB 3363'
H.B.
Lone Pine Cr
13-12-30-
KB 32
13.75 mi.
9.0 mi.
?
DATUM: TOP OF CYCLE A

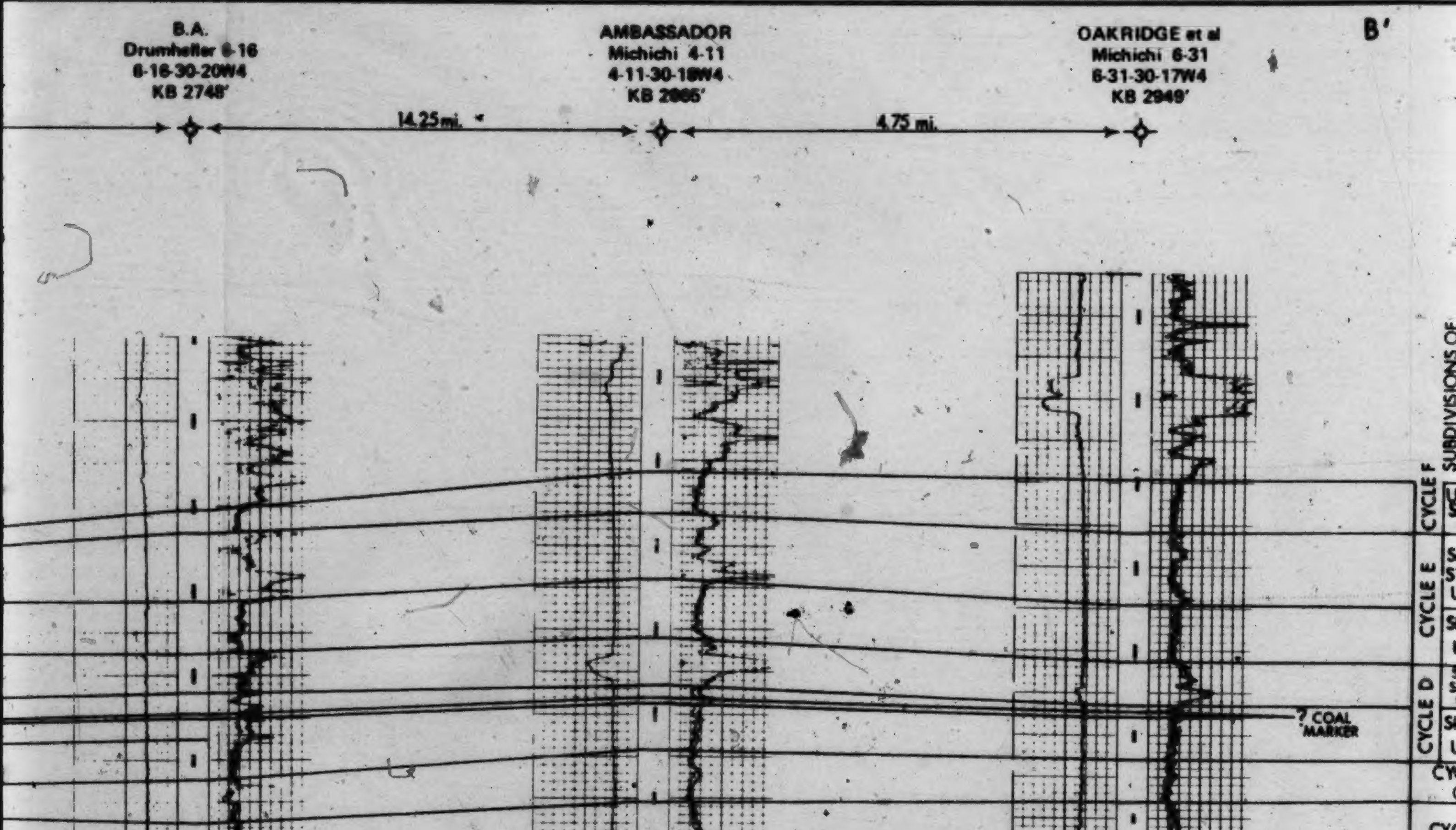
1 OF


H.B.
Lone Pine Creek 13-12
13-12-30-28W4
KB 3288'
H.B.
Olds 10-21
10-21-30-27W4
KB 3080'
DECALTA - MOBIL
Swalwell 12-26
12-26-30-25W4
KB 2965'
mi.
3.75 mi.
13.50 mi.
8.75
?

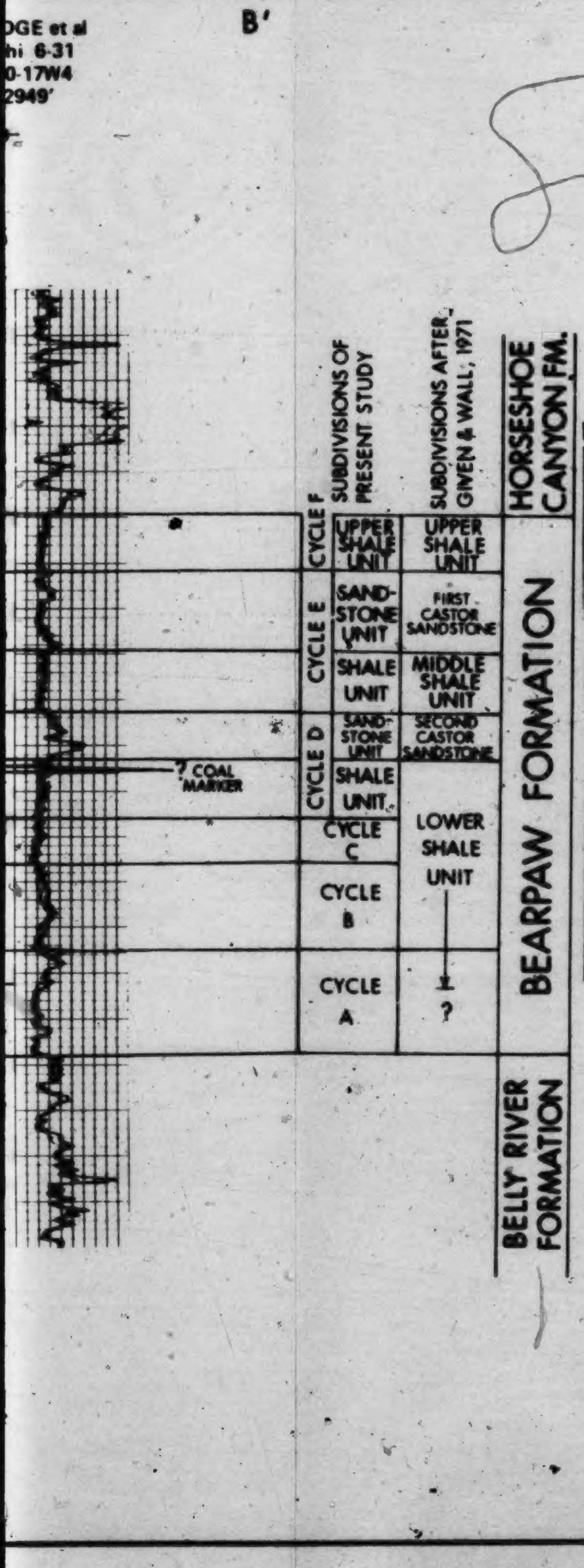
2 OF

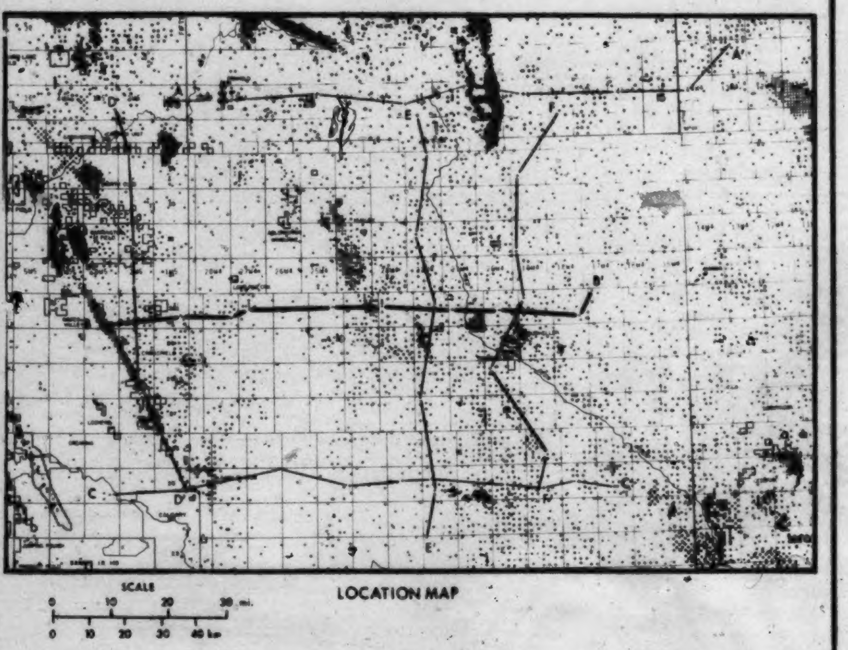

LTA - MOBIL
well 12-26
6-30-25W4
B 2985'
8.75 mi.
GREAT PLAINS
Choqua Three 14-19
14-19-30-23W4
KB 2823'
12.25 mi.
CAMERINA
Ghost Pine 11-18
11-18-30-21W4
KB 2672'
7.75 mi.
B.A.
Drumheller 6-1
6-16-30-20W4
KB 2748'
?
?
?

3 OF

B.A.
Drumheller 6-16
6-16-30-20W4
KB 2748'
AMBASSADOR
Michichi 4-11
4-11-30-18W4
KB 2865'
OAKRIDGE et al
Michichi 6-31
6-31-30-17W4
KB 2949'
B'
14.25 mi.
4.75 mi.
DATUM: TOP OF CYCLE A
? COAL MARKER
SUBDIVISIONS OF
CYCLE F
CYCLE E
CYCLE D

4OF


DGE et al
hi 6-31
0-17W4
2949'
B'
? COAL MARKER
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
HORSESHOE CANYON FM.
CYCLE F
UPPER SHALE UNIT
UPPER SHALE UNIT
CYCLE E
SAND-STONE UNIT
FIRST CASTOR SANDSTONE
SHALE UNIT
MIDDLE SHALE UNIT
CYCLE D
SAND-STONE UNIT
SECOND CASTOR SANDSTONE
SHALE UNIT
CYCLE C
CYCLE B
CYCLE A
LOWER SHALE UNIT
?
BEARPAW FORMATION
BELLY RIVER FORMATION


A'
B'
C
C'
D
D'
E
E'
SCALE
0 10 20 30 mi.
0 10 20 30 40 km

LOCATION MAP

FIGURE 7.

STRATIGRAPHIC CROSS SECTION
B-B'
CEGO Westcott 6-3 to OAKRIDGE Michichi 6-31

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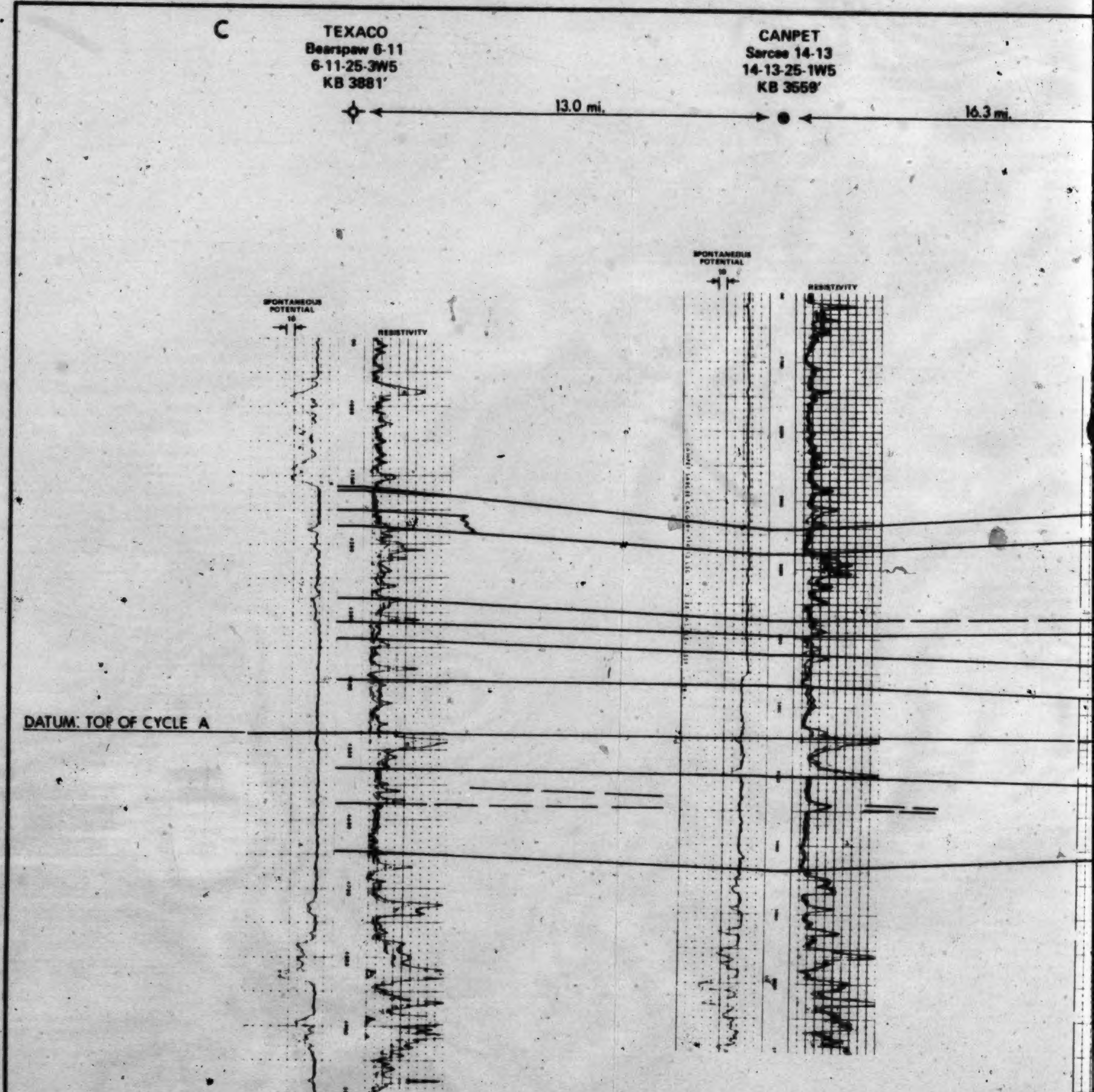
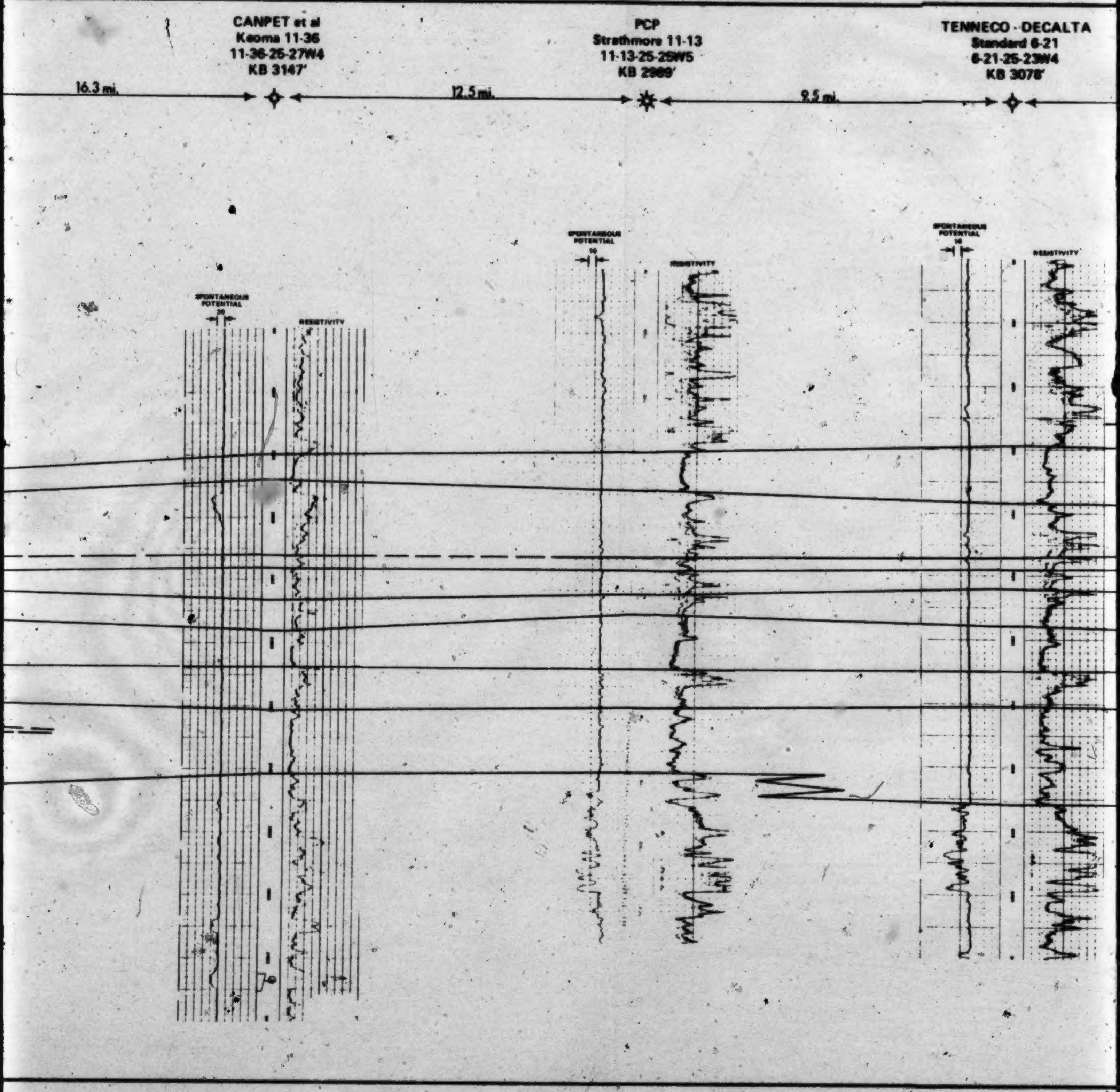
University of Alberta
1980

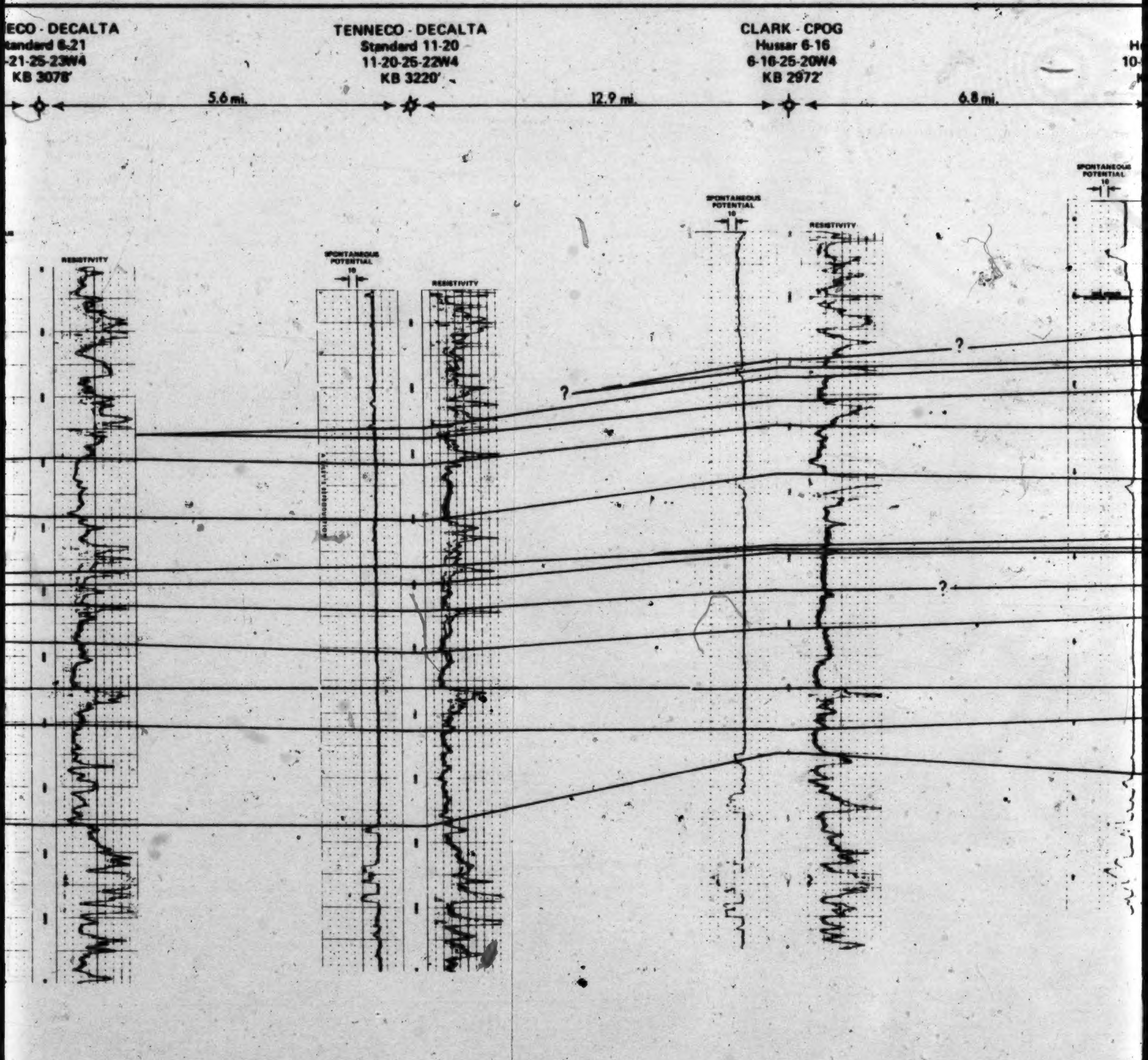
5OF5


C
TEXACO
Bearspaw 6-11
6-11-25-3W5
KB 3881'
13.0 mi.
CANPET
Sarcee 14-13
14-13-25-1W5
KB 3559'
16.3 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
DATUM: TOP OF CYCLE A

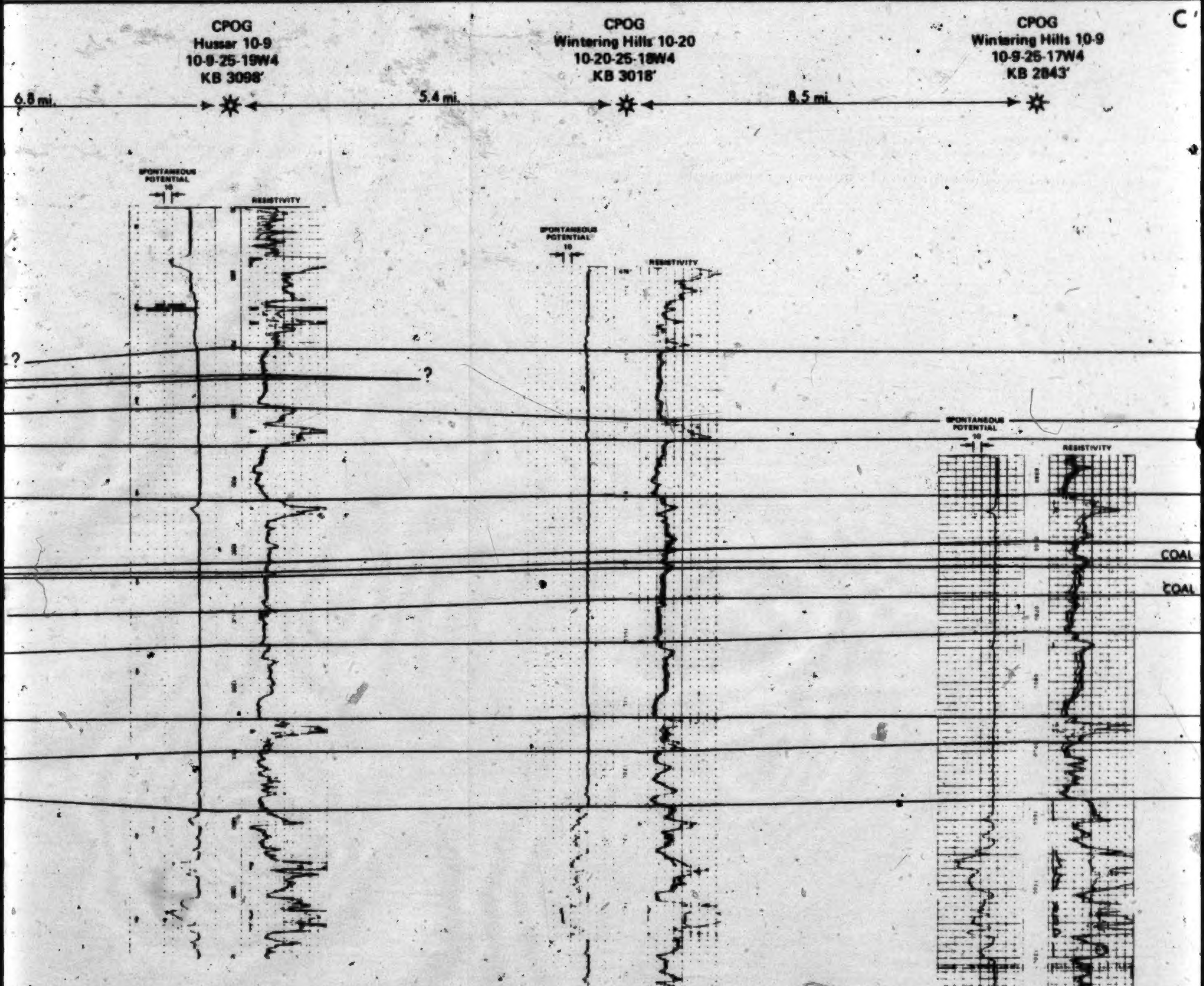
1 OF


16.3 mi.
CANPET et al
Keoma 11-36
11-36-25-27W4
KB 3147'
12.5 mi.
PCP
Strathmore 11-13
11-13-25-25W5
KB 2989'
9.5 mi.
TENNECO - DECALTA
Standard 6-21
6-21-25-23W4
KB 3078'
SPONTANEOUS POTENTIAL
RESISTIVITY
SPONTANEOUS POTENTIAL
RESISTIVITY
SPONTANEOUS POTENTIAL
RESISTIVITY

2 OF


ECO - DECALTA
tandard 6-21
-21-25-23W4
KB 3078'
TENNECO - DECALTA
Standard 11-20
11-20-25-22W4
KB 3220'
CLARK - CPOG
Hussar 6-16
6-16-25-20W4
KB 2972'
H
10-
5.6 mi.
12.9 mi.
6.8 mi.
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
?
?
?

3 OF


C'
CPOG
Hussar 10-9
10-9-25-19W4
KB 3098'
CPOG
Wintering Hills 10-20
10-20-25-18W4
KB 3018'
CPOG
Wintering Hills 10-9
10-9-25-17W4
KB 2843'
6.8 mi.
5.4 mi.
8.5 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
?
?
COAL
COAL

4OF

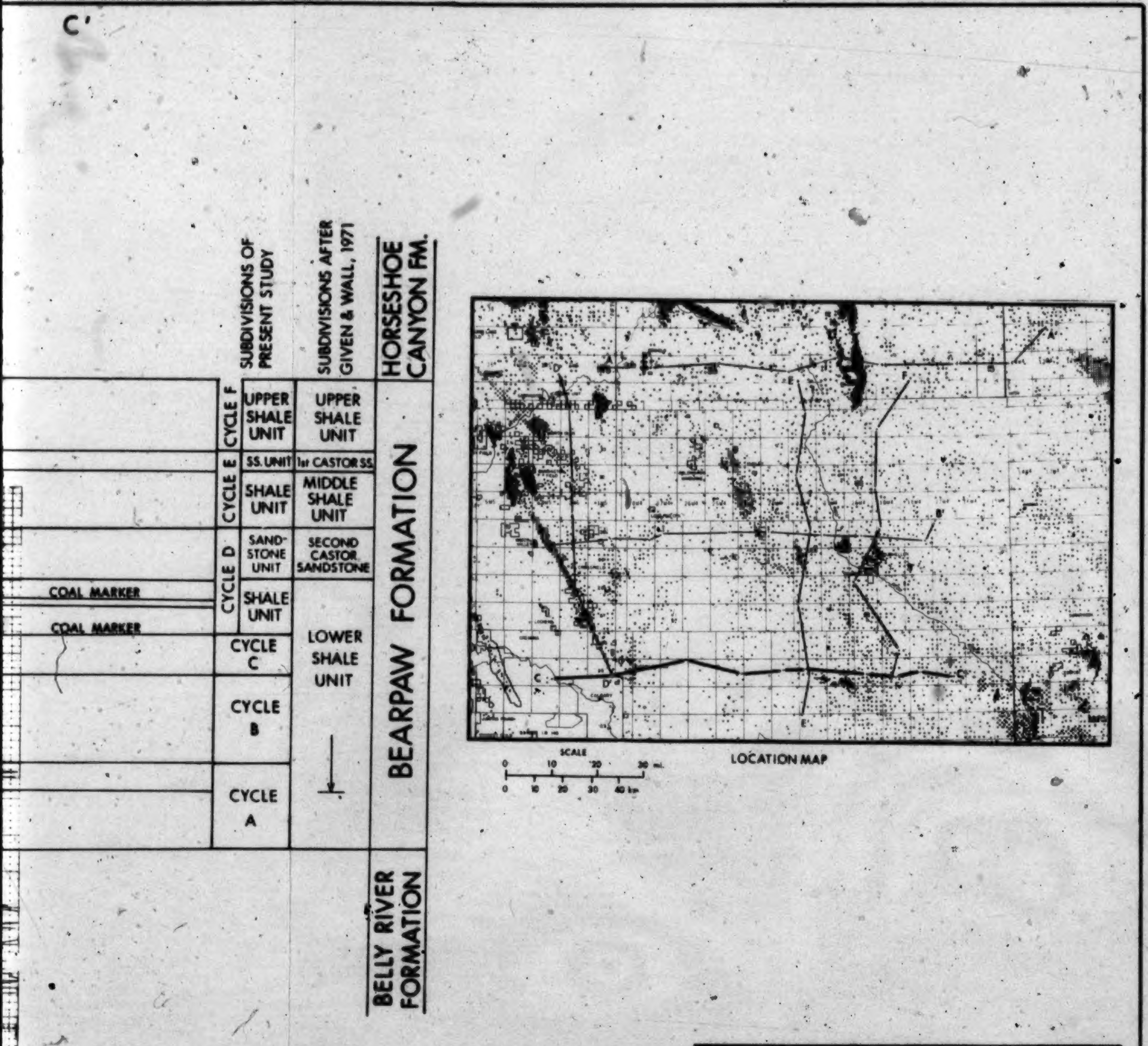

C'
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
HORSESHOE CANYON FM.
CYCLE F
UPPER SHALE UNIT
UPPER SHALE UNIT
CYCLE E
SS. UNIT
1st CASTOR SS.
SHALE UNIT
MIDDLE SHALE UNIT
CYCLE D
SAND-STONE UNIT
SECOND CASTOR SANDSTONE
COAL MARKER
SHALE UNIT
COAL MARKER
CYCLE C
LOWER SHALE UNIT
CYCLE B
CYCLE A
BEARPAW FORMATION
BELLY RIVER FORMATION
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
SCALE
0
10
20
30 mi.
0
10
20
30
40 km
LOCATION MAP

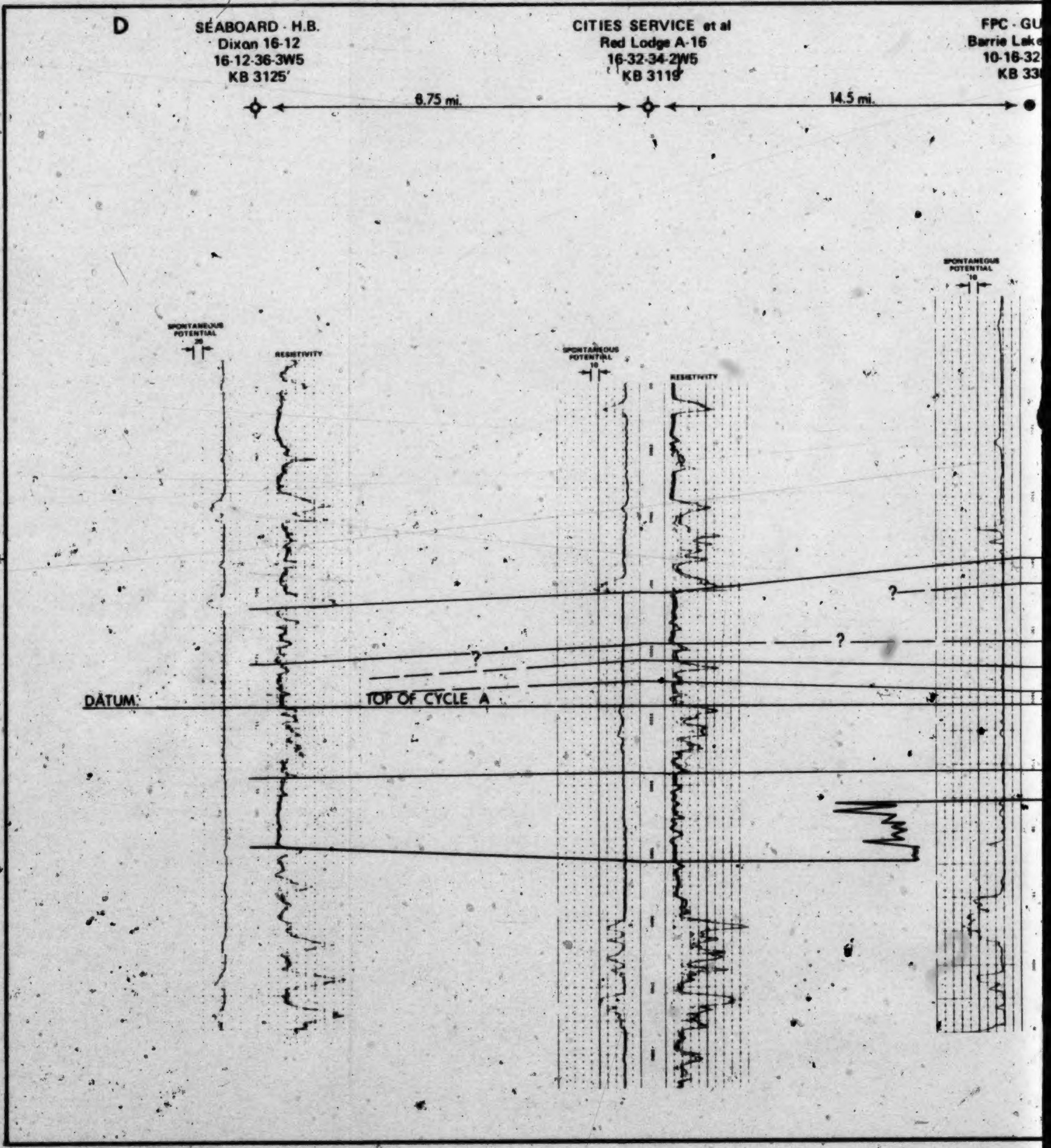
FIGURE 8.

STRATIGRAPHIC CROSS SECTION
C-C'

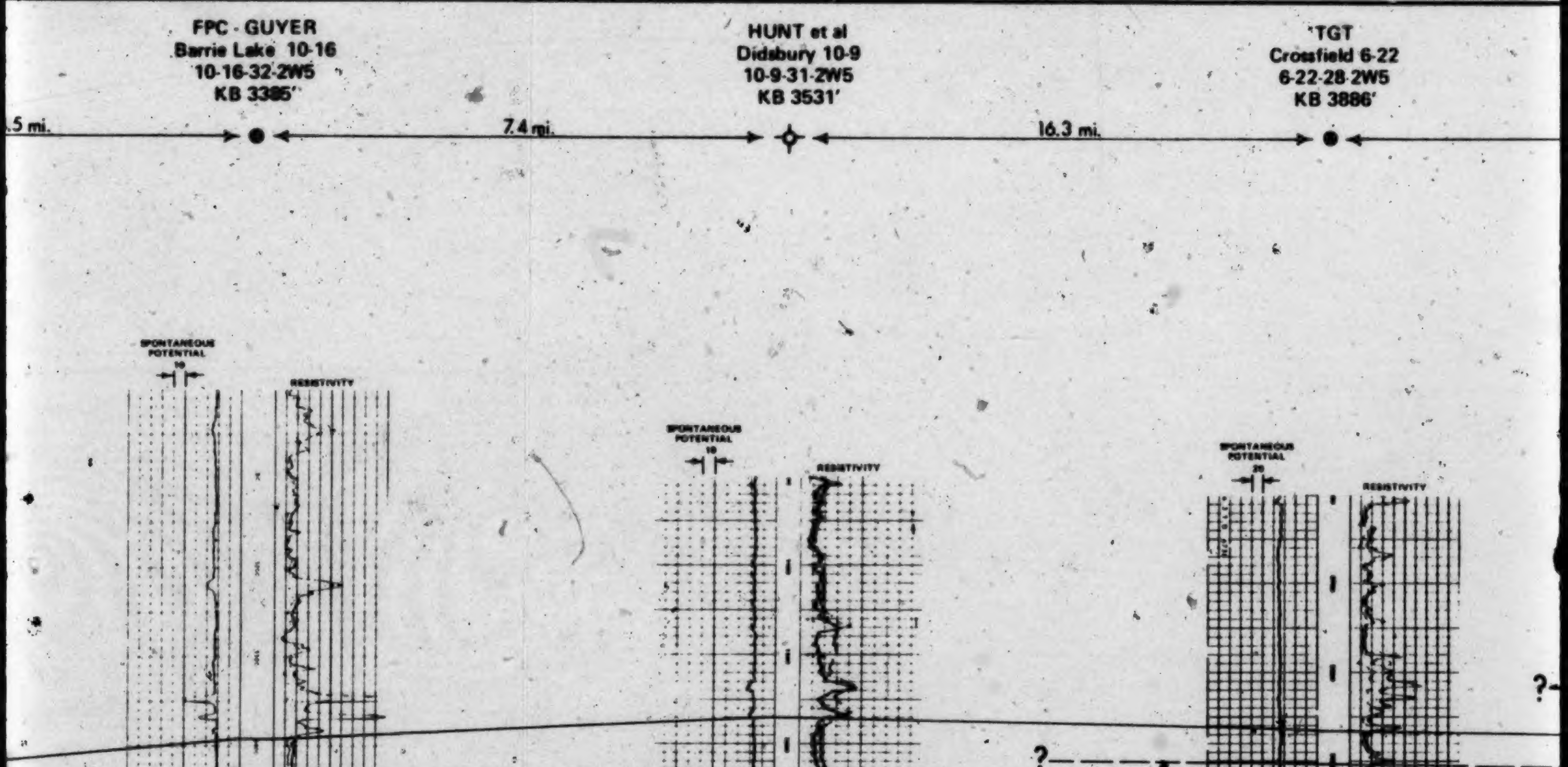
TEXACO Bearspaw 6-11 to CPOG Winter H. 10-9

Antoine G.E. Habib
University of Alberta
1980

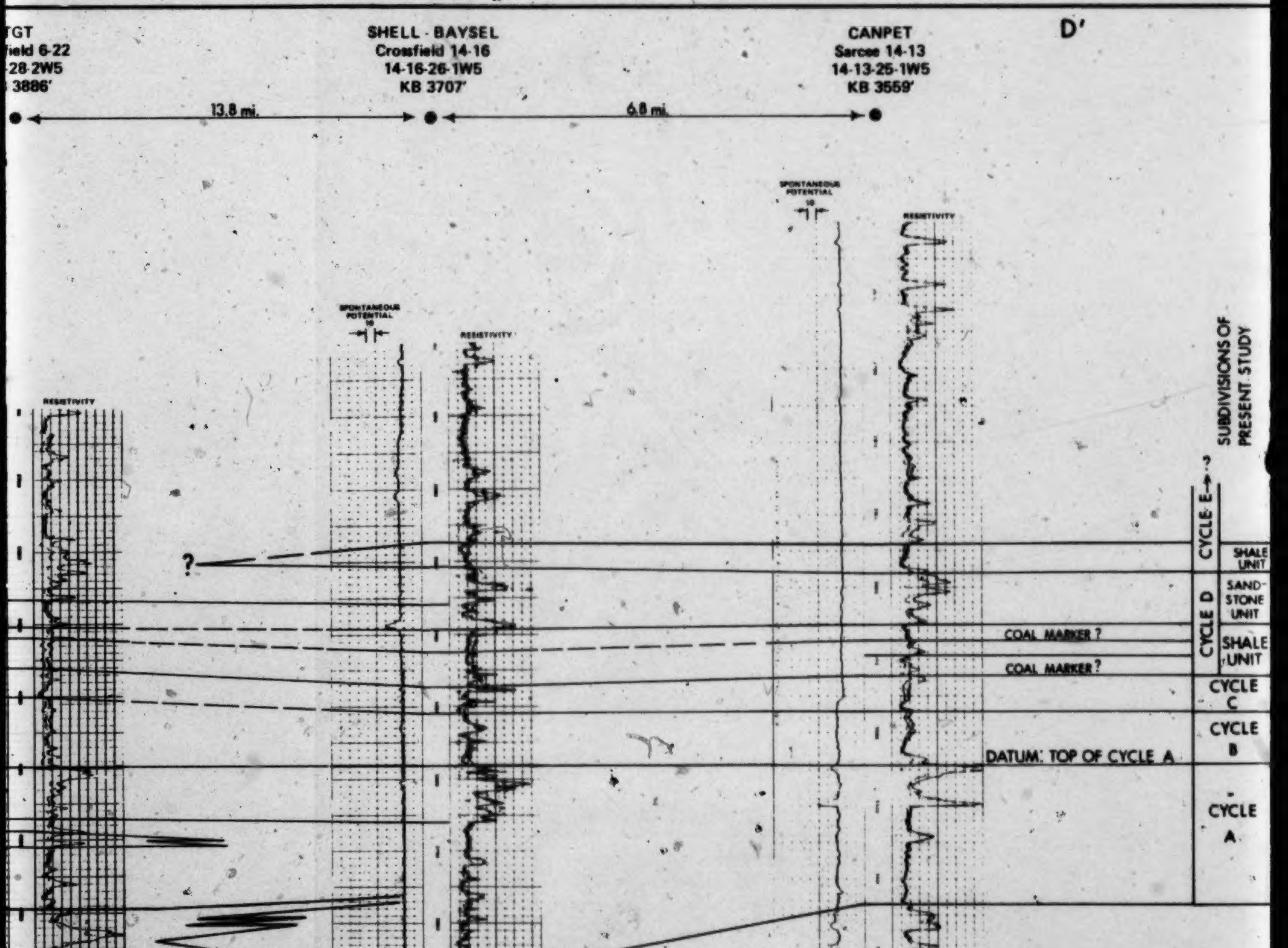
5OF5


D
SEABOARD · H.B.
Dixon 16-12
16-12-36-3W5
KB 3125'
CITIES SERVICE et al
Red Lodge A-16
16-32-34-2W5
KB 3119'
FPC · GU
Barrie Lake
10-16-32
KB 33
8.75 mi.
14.5 mi.
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
?
?
?
DATUM:
TOP OF CYCLE A

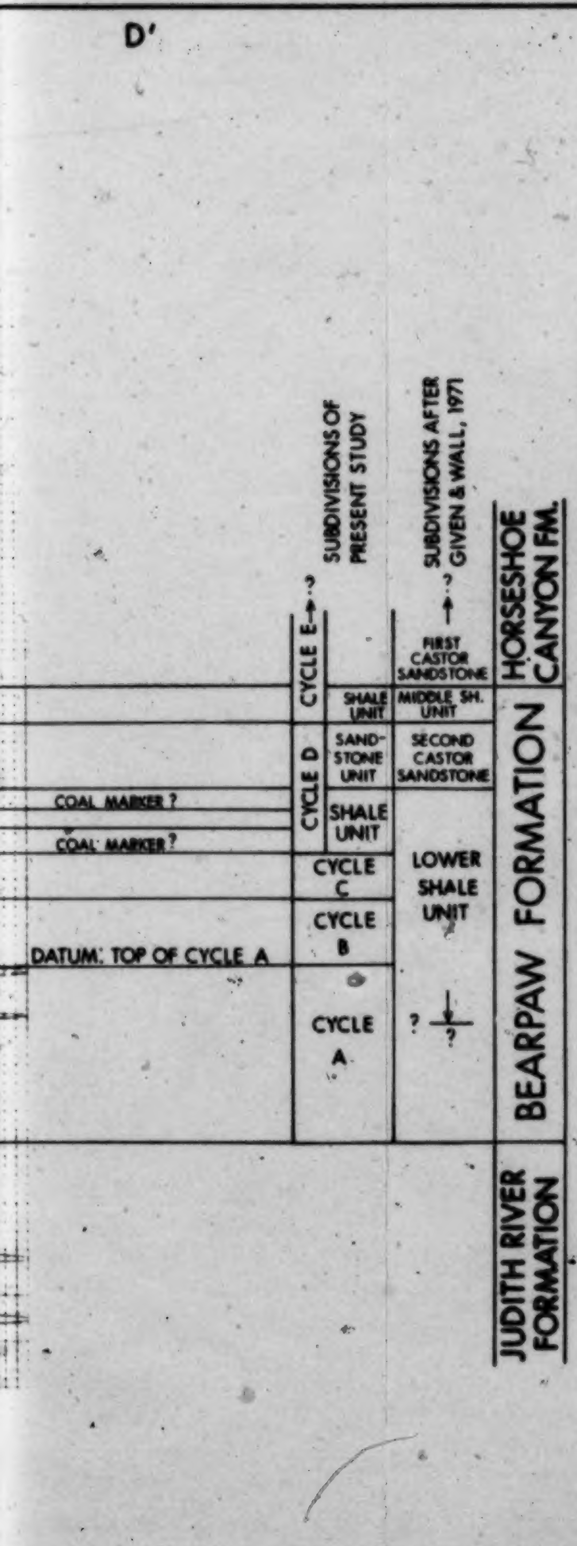
1 OF


FPC - GUYER
Barrie Lake 10-16
10-16-32-2W5
KB 3385'
HUNT et al
Didsbury 10-9
10-9-31-2W5
KB 3531'
'TGT
Crossfield 6-22
6-22-28-2W5
KB 3886'
.5 mi.
7.4 mi.
16.3 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
?
?
?
?
?

3 OF


TGT
ield 6-22
28-2W5
3886'
13.8 mi.
SHELL - BAYSEL
Crossfield 14-16
14-16-26-1W5
KB 3707'
6.8 mi.
CANPET
Sarcee 14-13
14-13-25-1W5
KB 3559'
D'
SPONTANEOUS POTENTIAL
10
RESISTIVITY
?
COAL MARKER ?
COAL MARKER ?
DATUM: TOP OF CYCLE A
SUBDIVISIONS OF PRESENT STUDY
CYCLE E→?
CYCLE D
SHALE UNIT
SANDSTONE UNIT
SHALE UNIT
CYCLE C
CYCLE B
CYCLE A

3OF


D'
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
CYCLE E →?
? ←
FIRST CASTOR SANDSTONE
HORSESHOE CANYON FM.
SHALE UNIT
MIDDLE SH. UNIT
CYCLE D
SAND-STONE UNIT
SECOND CASTOR SANDSTONE
COAL MARKER ?
SHALE UNIT
COAL MARKER ?
CYCLE C
LOWER SHALE UNIT
CYCLE B
DATUM: TOP OF CYCLE A
CYCLE A
? ?
BEARPAW FORMATION
JUDITH RIVER FORMATION

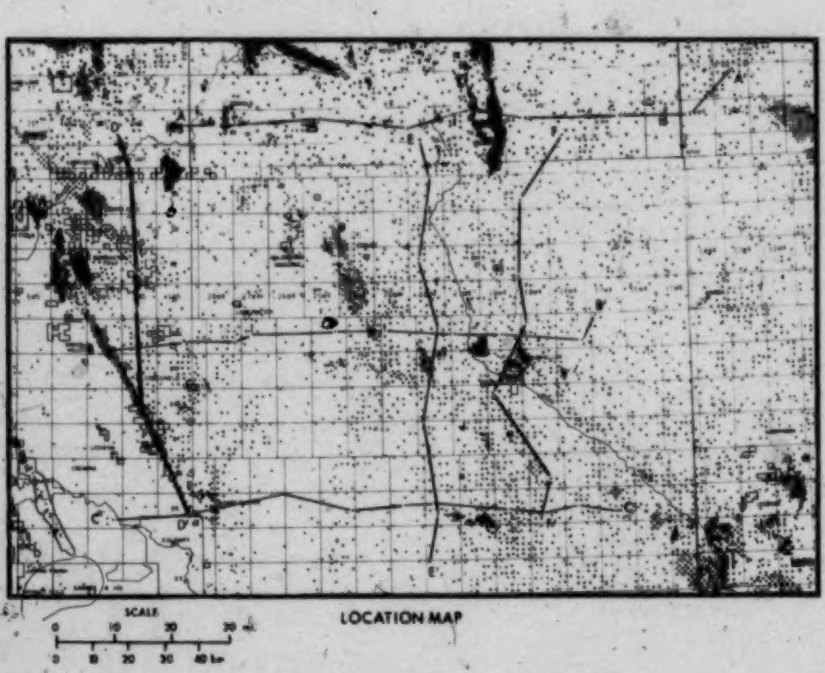

SCALE
0 10 20 30 mi
0 10 20 30 40 km
LOCATION MAP

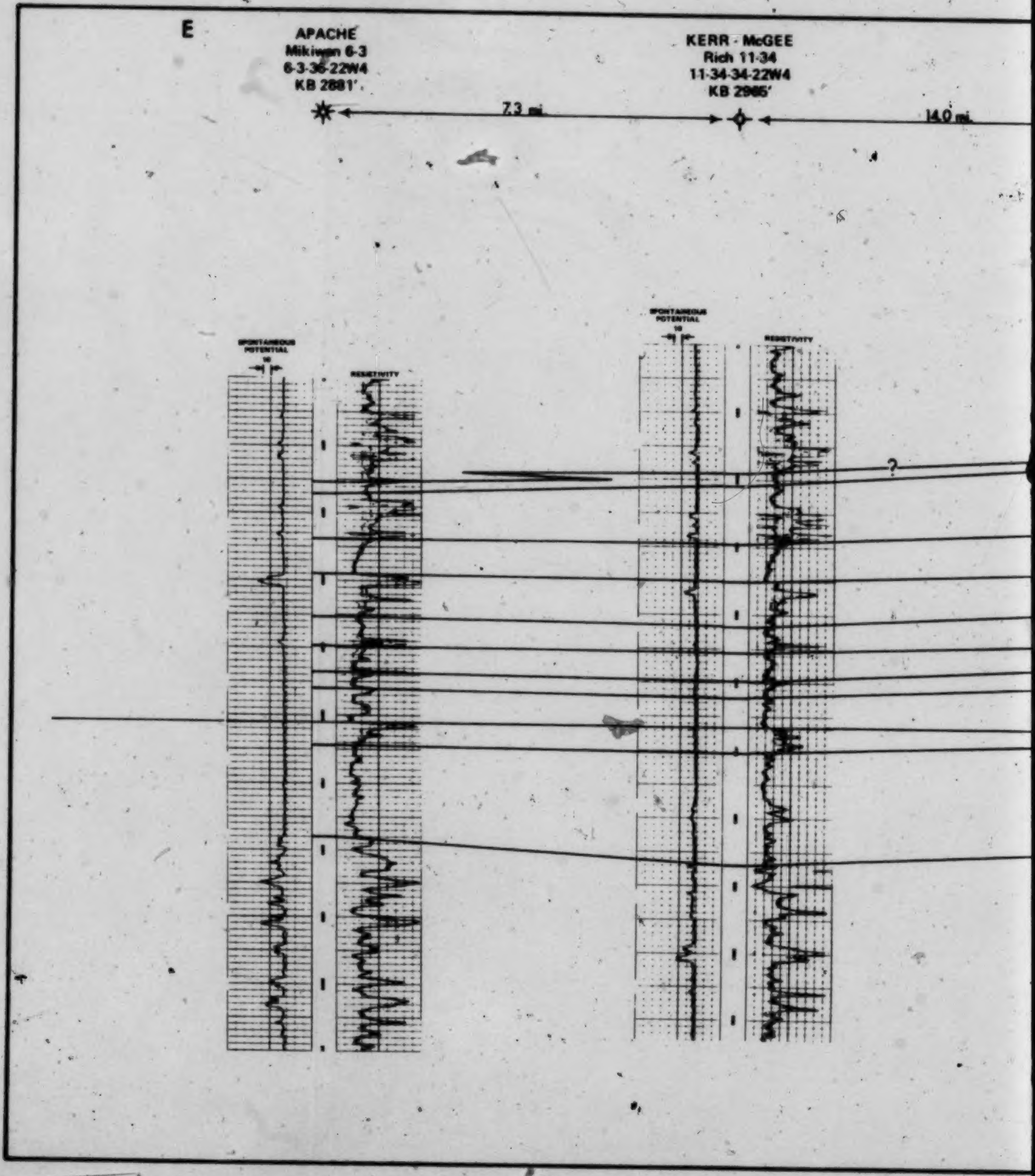
FIGURE 9

STRATIGRAPHIC CROSS SECTION D-D'

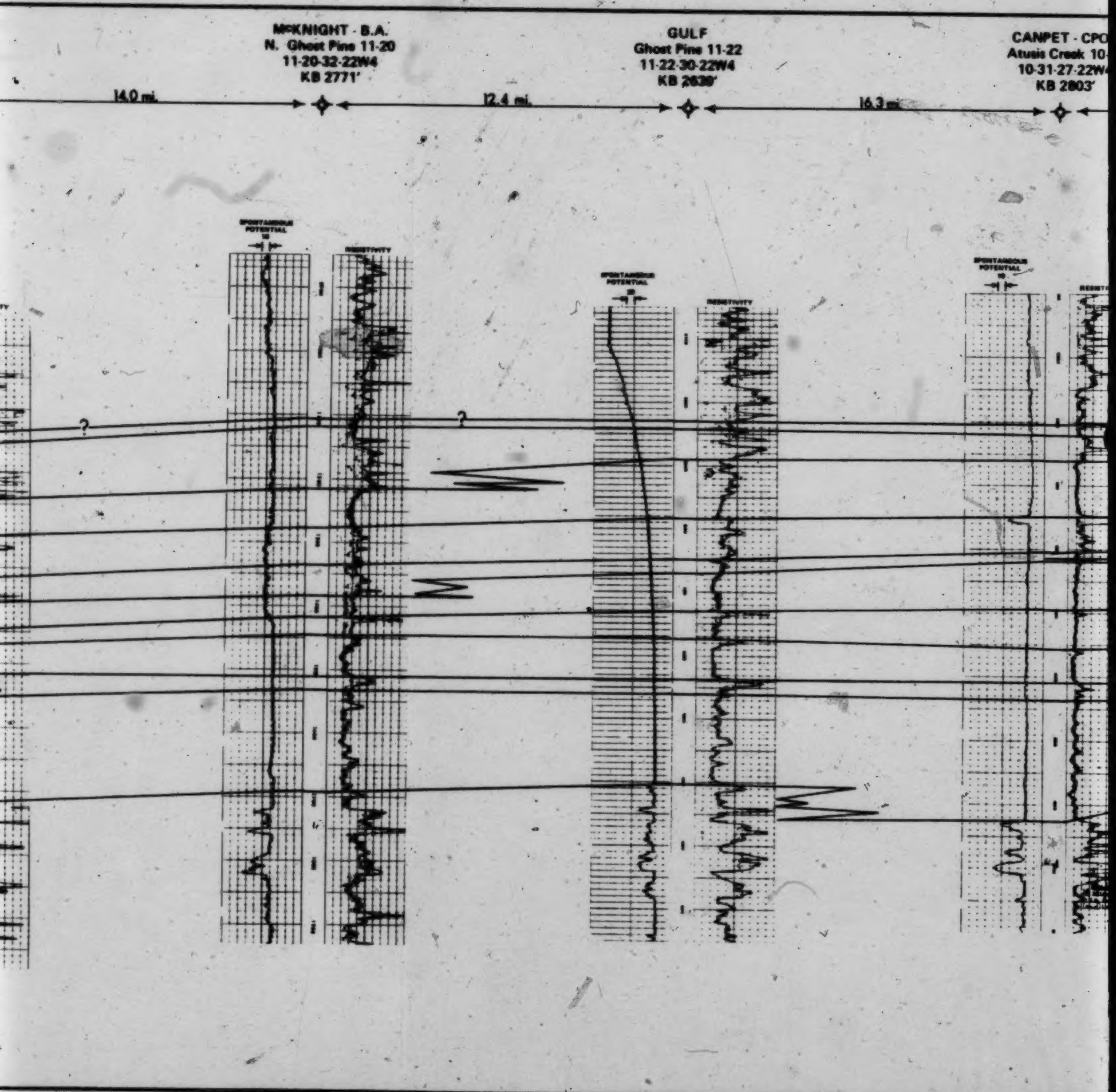
SEABOARD Dixon 16-12 to CANPET Sarcee 14-13

Antoine G.E. Habib
University of Alberta
1980

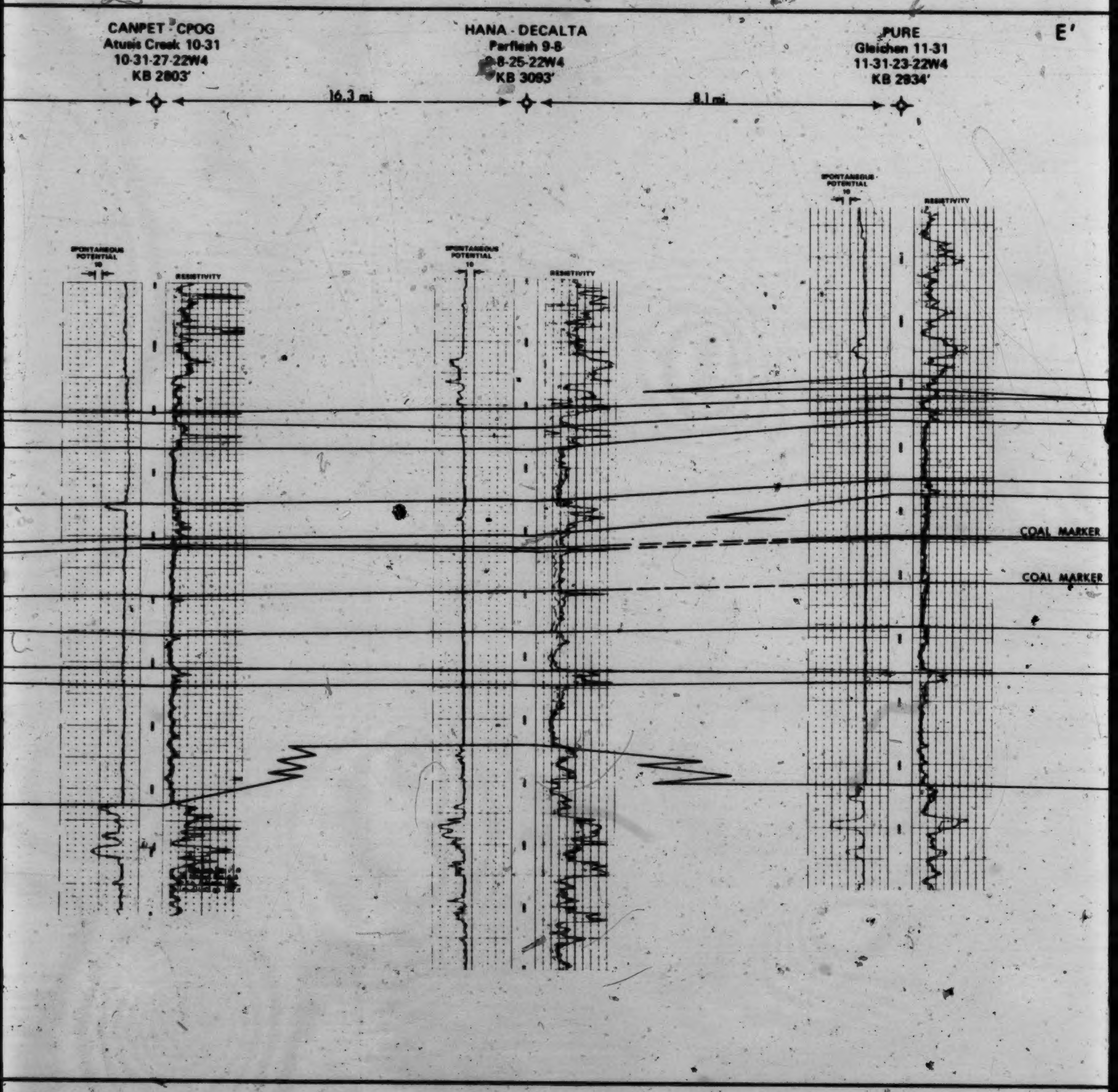
4 of 4


E
APACHE
Mikiwan 6-3
6-3-36-22W4
KB 2881'
KERR - McGEE
Rich 11-34
11-34-34-22W4
KB 2965'
7.3 mi.
14.0 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
?

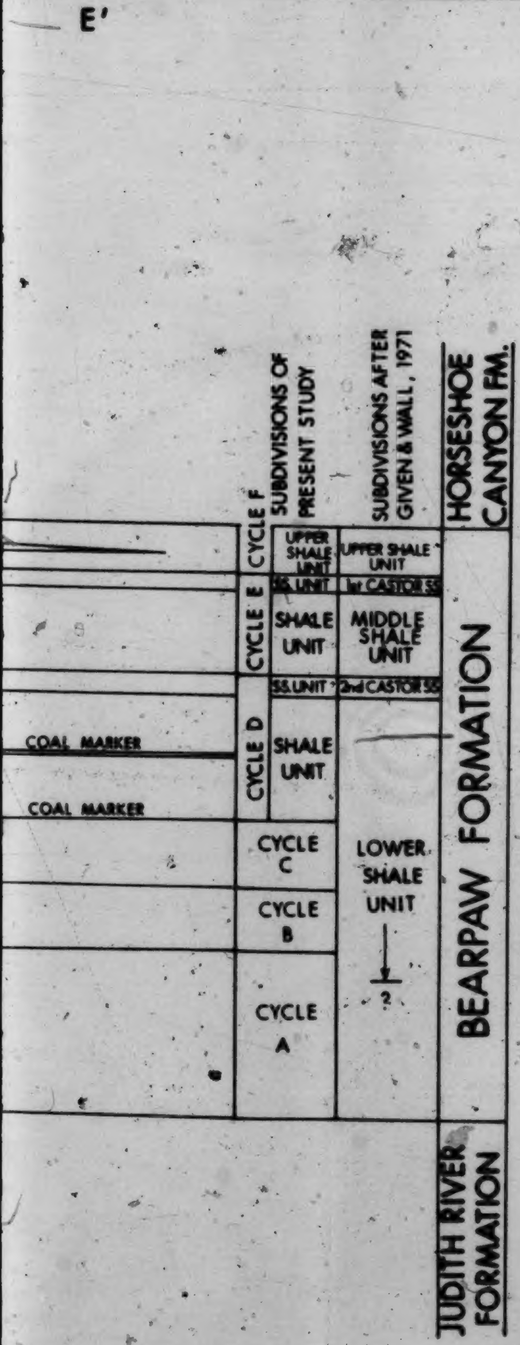
1 OF


14.0 mi.
McKNIGHT - B.A.
N. Ghost Pine 11-20
11-20-32-22W4
KB 2771'
12.4 mi.
GULF
Ghost Pine 11-22
11-22-30-22W4
KB 2630'
16.3 mi.
CANPET - CPO
Atusis Creek 10-
10-31-27-22W
KB 2803'
SPONTANEOUS POTENTIAL
RESISTIVITY
?
?

20F


CANPET - CPOG
Atusis Creek 10-31
10-31-27-22W4
KB 2803'
HANA - DECALTA
Parflesh 9-8
9-8-25-22W4
KB 3093'
PURE
Gleichen 11-31
11-31-23-22W4
KB 2834'
E'
16.3 mi.
8.1 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
COAL MARKER
COAL MARKER

3 OF


E'
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
HORSESHOE CANYON FM.
CYCLE F
UPPER SHALE UNIT
UPPER SHALE UNIT
CYCLE E
SS. UNIT
1st CASTOR SS
SHALE UNIT
MIDDLE SHALE UNIT
CYCLE D
SS. UNIT
2nd CASTOR SS
COAL MARKER
SHALE UNIT
COAL MARKER
CYCLE C
CYCLE B
CYCLE A
LOWER SHALE UNIT
?
BEARPAW FORMATION
JUDITH RIVER FORMATION

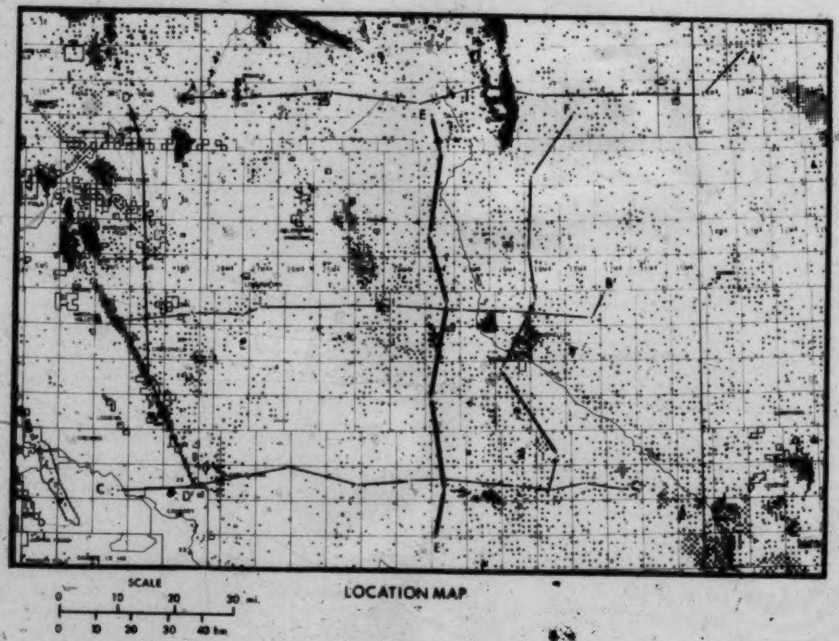

C
D
E
E'
SCALE
0 10 20 30 mi.
0 10 20 30 40 km
LOCATION MAP

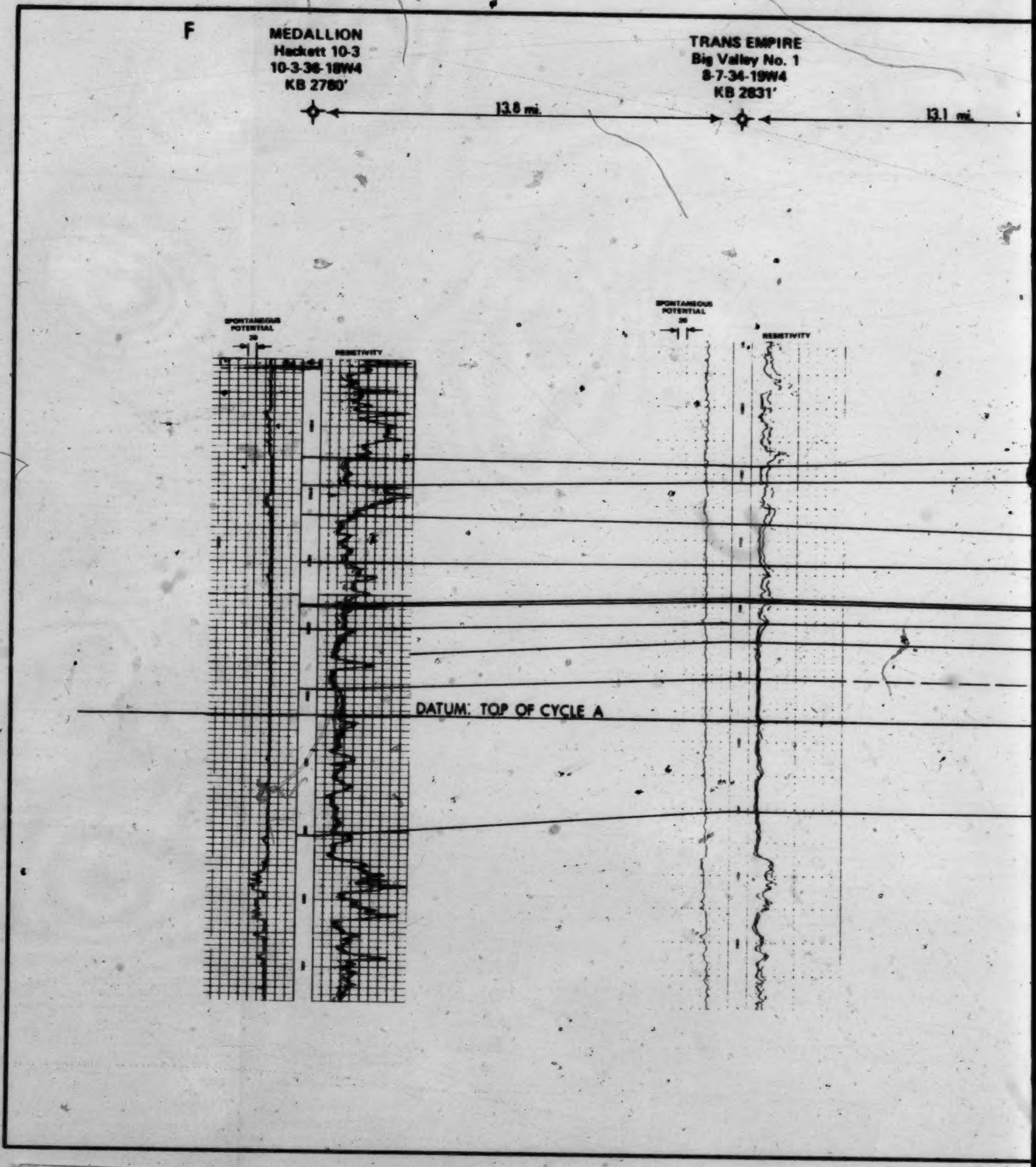
FIGURE 10.

STRATIGRAPHIC CROSS SECTION E-E'

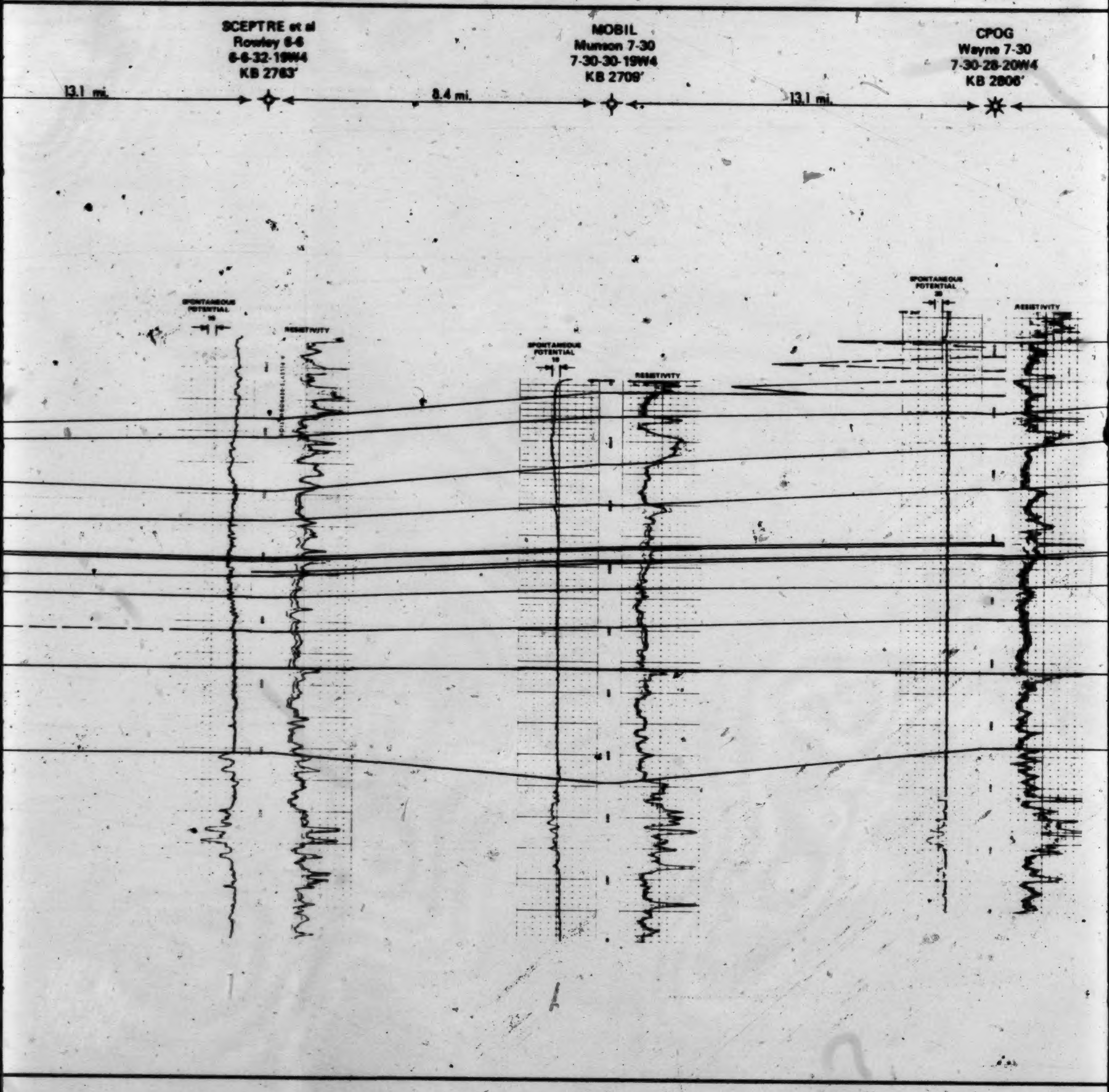
APACHE Mikwan 6-3 to PURE Gleichen 11-31

Antoine G.E. Habib
University of Alberta
1980

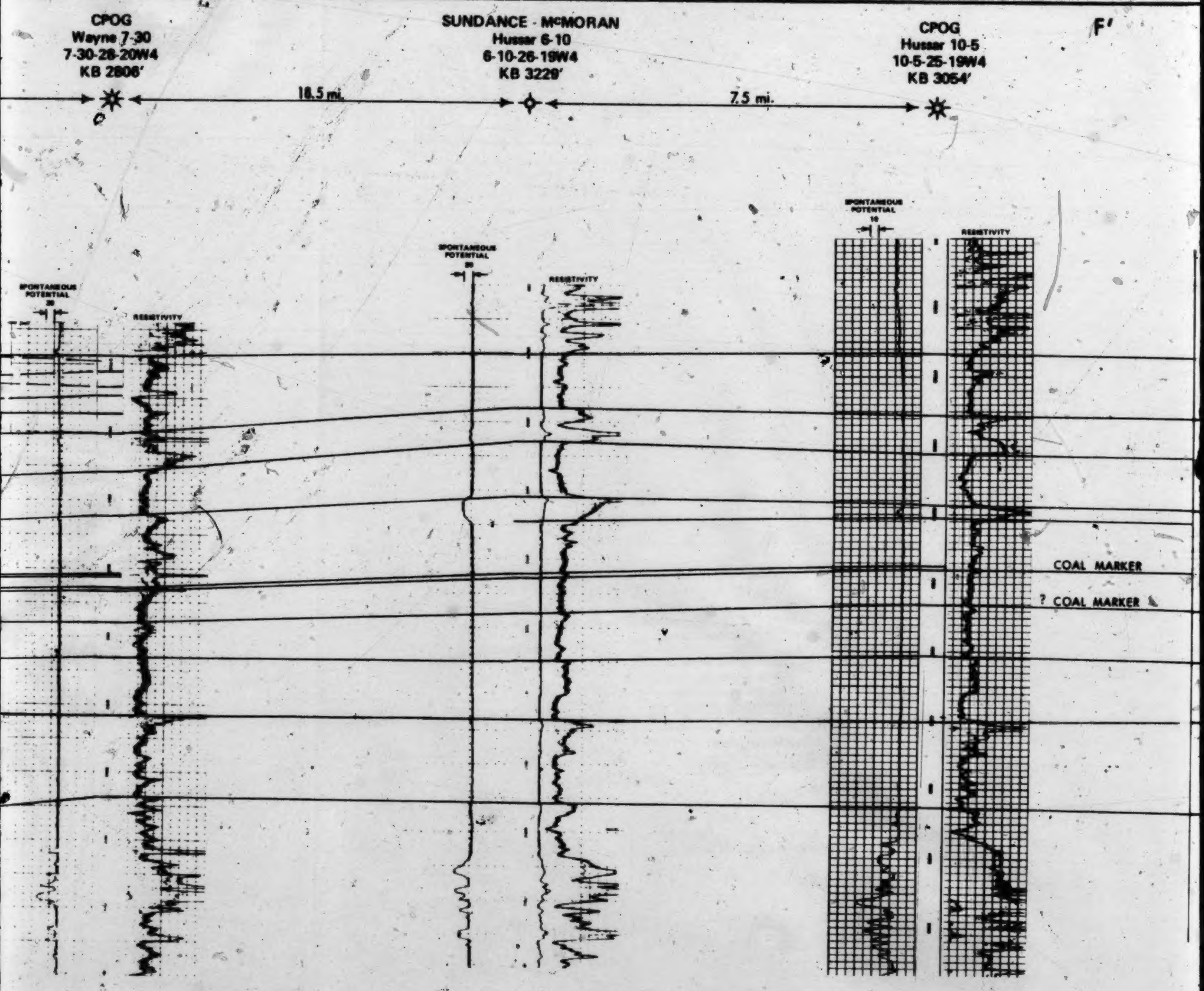
4 of 4


F
MEDALLION
Hackett 10-3
10-3-36-18W4
KB 2780'
13.8 mi.
TRANS EMPIRE
Big Valley No. 1
8-7-34-19W4
KB 2831'
13.1 mi.
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
DATUM: TOP OF CYCLE A

1 OF


SCEPTRE et al
Rowley 6-6
6-6-32-19W4
KB 2763'
MOBIL
Munson 7-30
7-30-30-19W4
KB 2709'
CPOG
Wayne 7-30
7-30-28-20W4
KB 2806'
13.1 mi.
8.4 mi.
13.1 mi.
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY

2OF


CPOG
Wayne 7-30
7-30-28-20W4
KB 2806′
16.5 mi.
SUNDANCE - McMORAN
Hussar 6-10
6-10-26-19W4
KB 3229′
7.5 mi.
CPOG
Hussar 10-5
10-5-25-19W4
KB 3054′
F′
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
20
RESISTIVITY
SPONTANEOUS POTENTIAL
10
RESISTIVITY
COAL MARKER
? COAL MARKER

3 OF

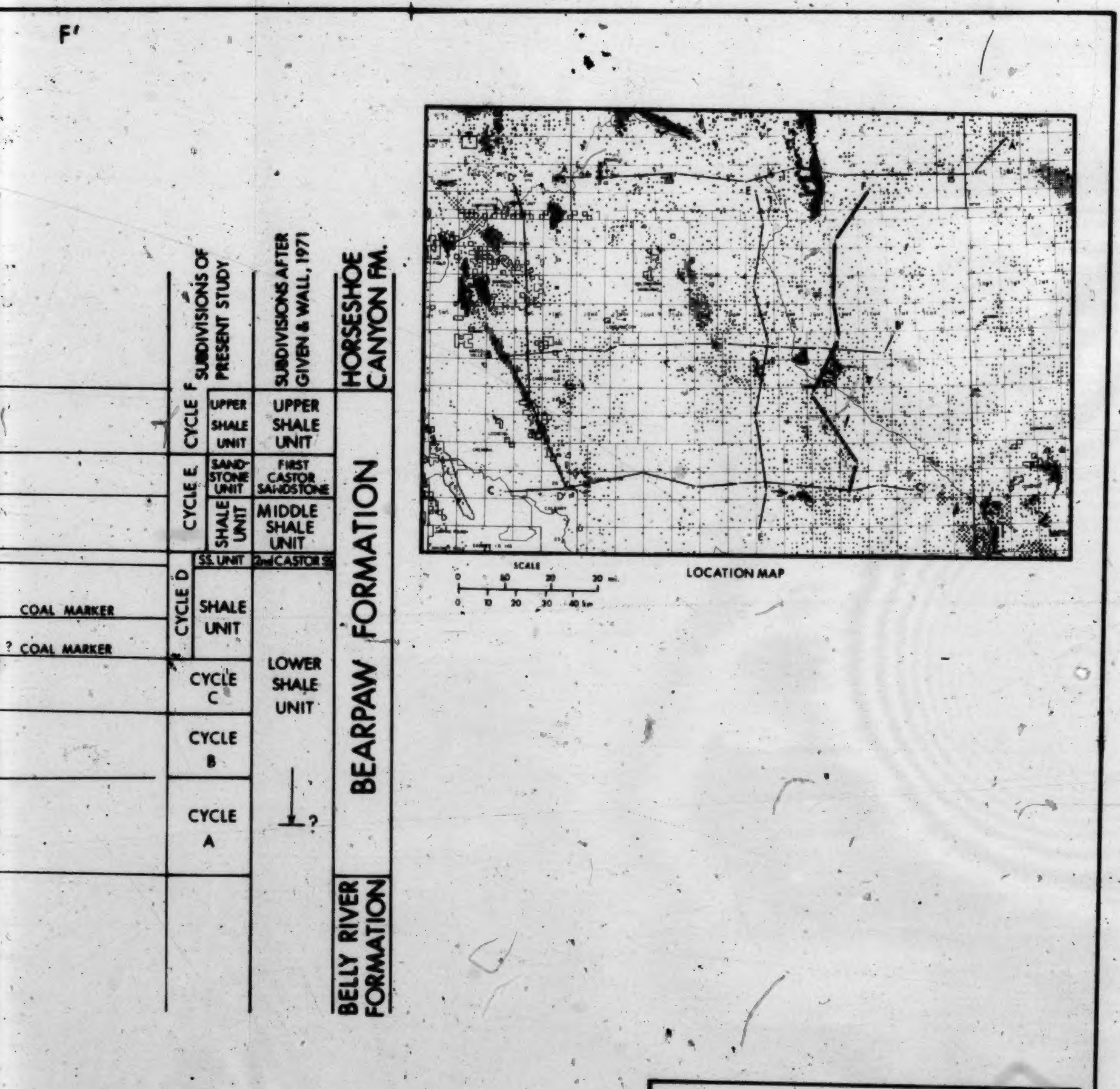
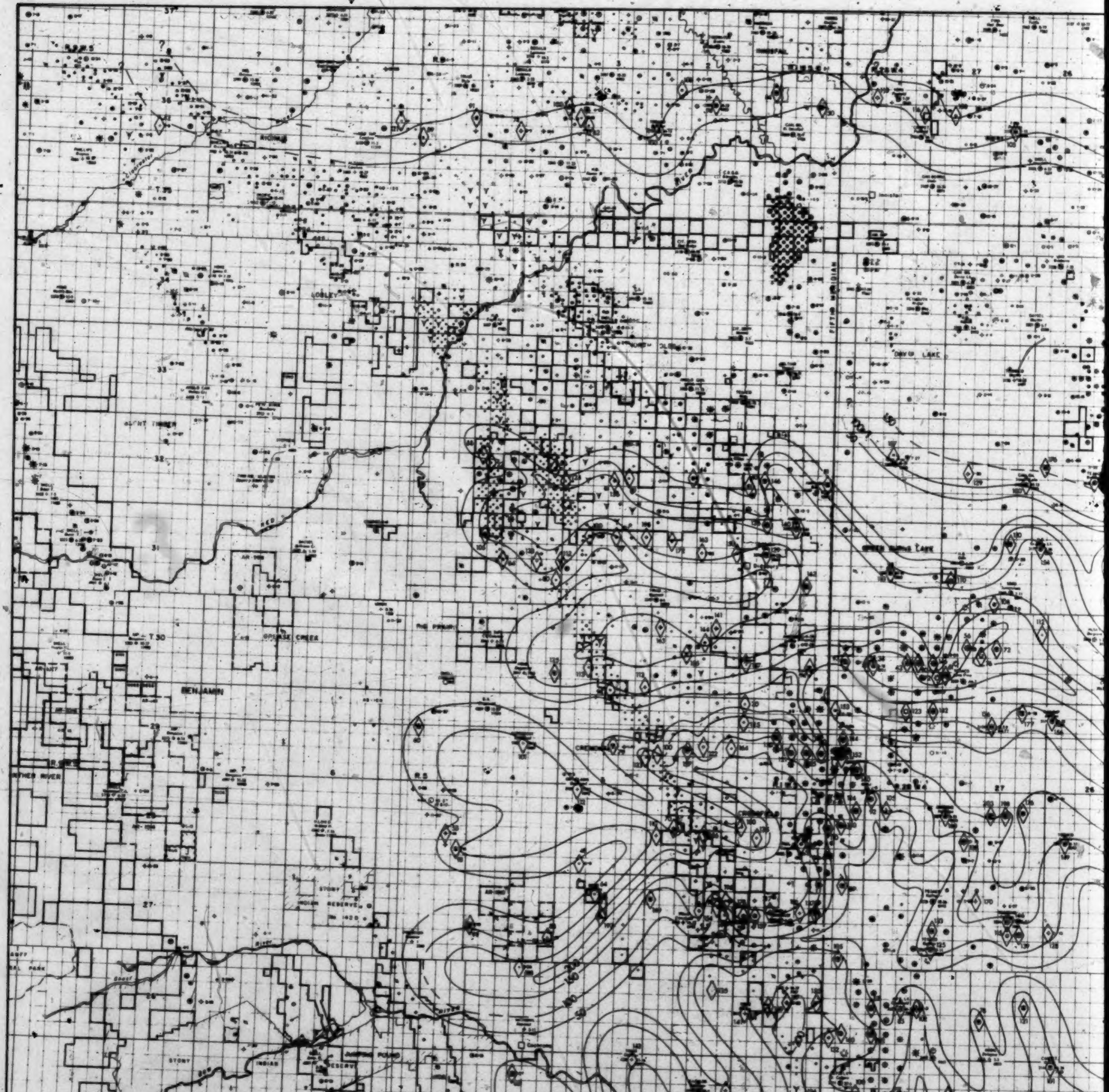

F'
SUBDIVISIONS OF PRESENT STUDY
SUBDIVISIONS AFTER GIVEN & WALL, 1971
HORSESHOE CANYON FM.
CYCLE F
UPPER SHALE UNIT
UPPER SHALE UNIT
CYCLE E.
SAND-STONE UNIT
FIRST CASTOR SANDSTONE
SHALE UNIT
MIDDLE SHALE UNIT
SS. UNIT
2nd CASTOR SS
CYCLE D
SHALE UNIT
COAL MARKER
? COAL MARKER
CYCLE C
CYCLE B
CYCLE A
LOWER SHALE UNIT
?
BEARPAW FORMATION
BELLY RIVER FORMATION
SCALE
0 10 20 30 mi
0 10 20 30 40 km
LOCATION MAP

FIGURE 11.

STRATIGRAPHIC CROSS SECTION
F-F'
MEDALLION Hacket 10-3 to C.P.O.G. Hussar 10-5

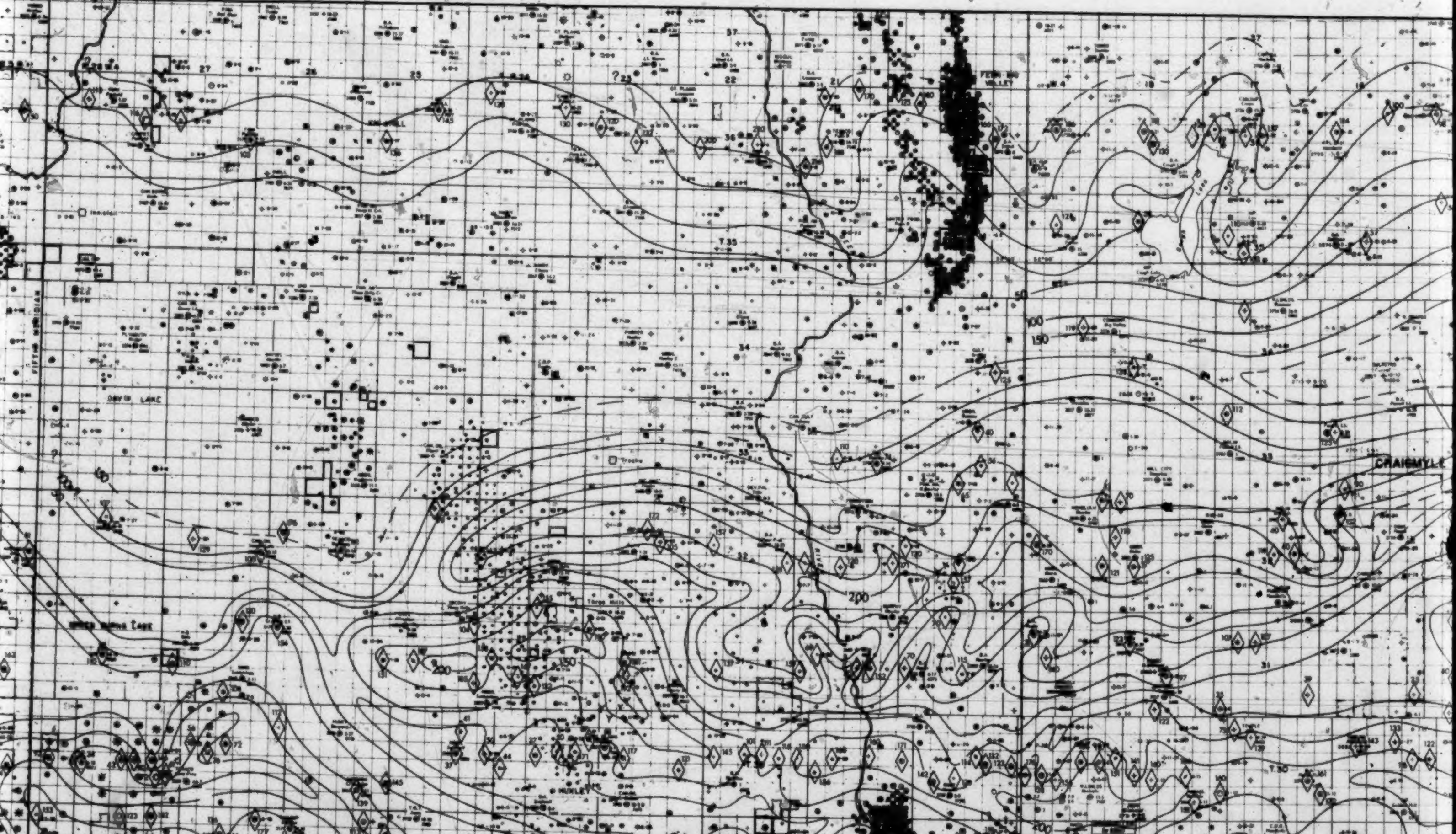
Antoine G.E. Habib
University of Alberta
1980

4 of 4



37
36
35
33
32
31
T.30
29
27
26
24
R.5
BENJAMIN
FIFTH MERIDIAN
DAVID LAKE
RIVER
STONY
INDIAN RESERVE
CALGARY

1 OF


CRAIGMYLE
DAVEY LAKE
T.35
T.30
200
150
100
50

2 OF

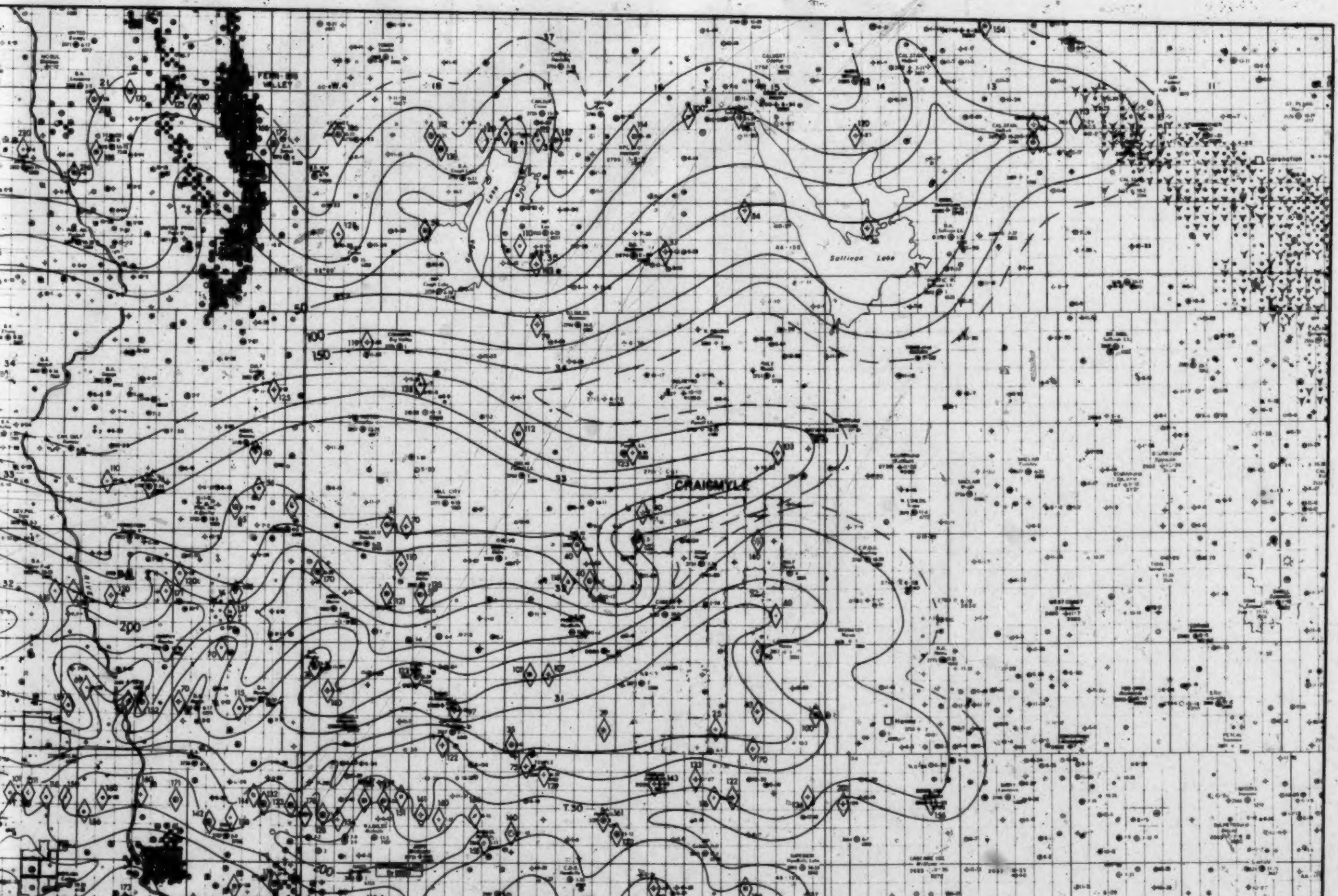

LEGEND
WELL CONTROL POINTS
ISOLITH LINE
INFERRED ISOLITH LINE
50 ISOLITH INTERVAL (in feet)
? QUESTIONABLE DUE TO LACK OF CONTROL
CRAIGMYLE
Sullivan Lake
DRUMHELLER
50
100
150
200

FIGURE 13.

Isolith Map of the Shale Unit, Cycle A

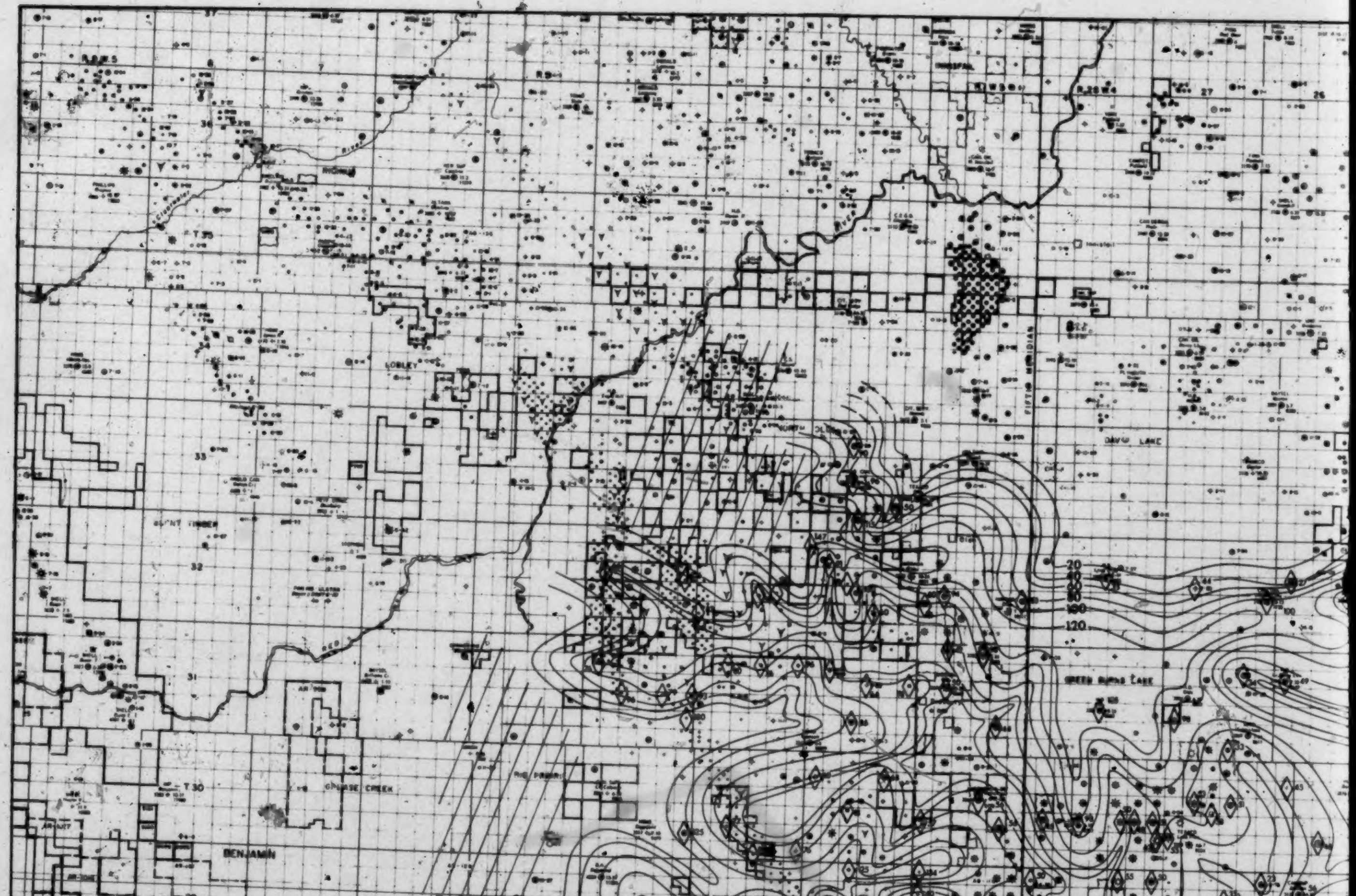
BEARPAW FORMATION

South Central Alberta

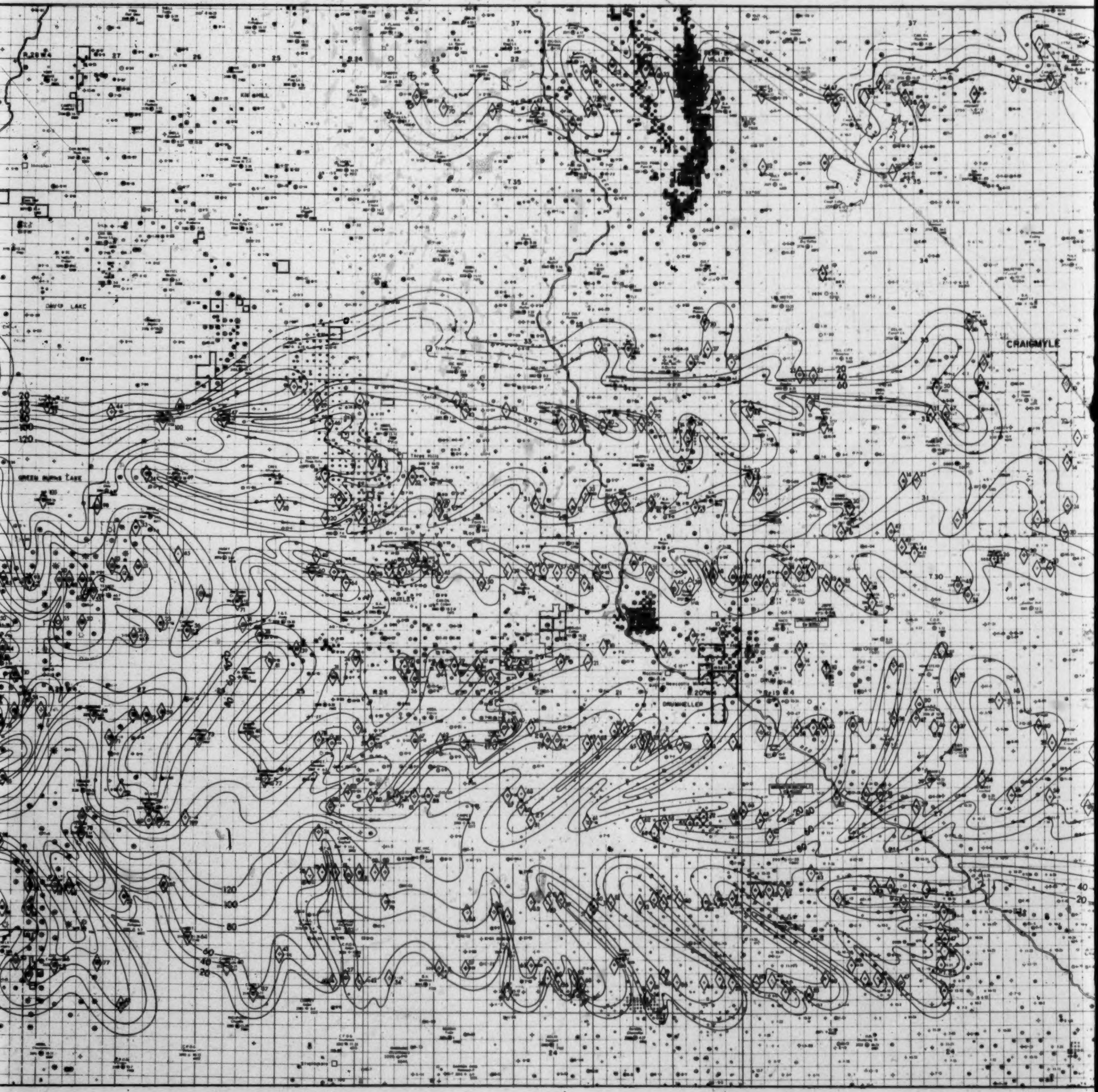
By Antoine G.E. Habib University of Alberta, 1981.

Scale: 1" = 32,000'

3 OF 3


33
32
31
T 30
BENJAMIN
29
27
24
ANTHER RIVER
FIFTH MERIDIAN
20
40
60
80
100
120
CALGARY

1 OF


CRAIGMYLE
DRUMHELLER
HUXLEY
DAVEY LAKE
T 35
T 30
20
40
60
80
100
120

2 OF

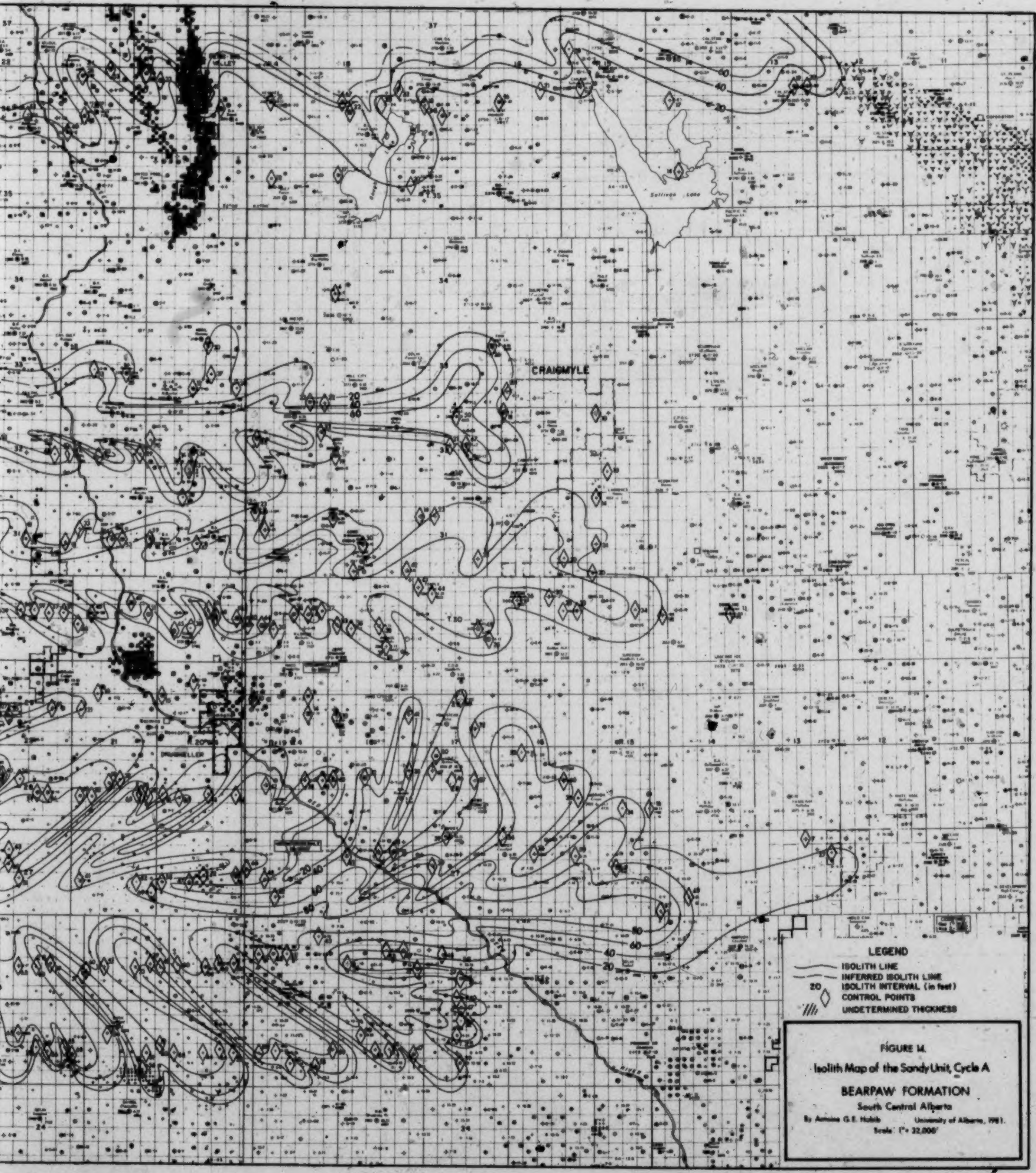

CRAIGMYLE
DRUMHELLER
Sullivan Lake
T.35
T.30
20
40
60
LEGEND
ISOLITH LINE
INFERRED ISOLITH LINE
20 ISOLITH INTERVAL (in feet)
CONTROL POINTS
UNDETERMINED THICKNESS

FIGURE 14.

Isolith Map of the Sandy Unit, Cycle A

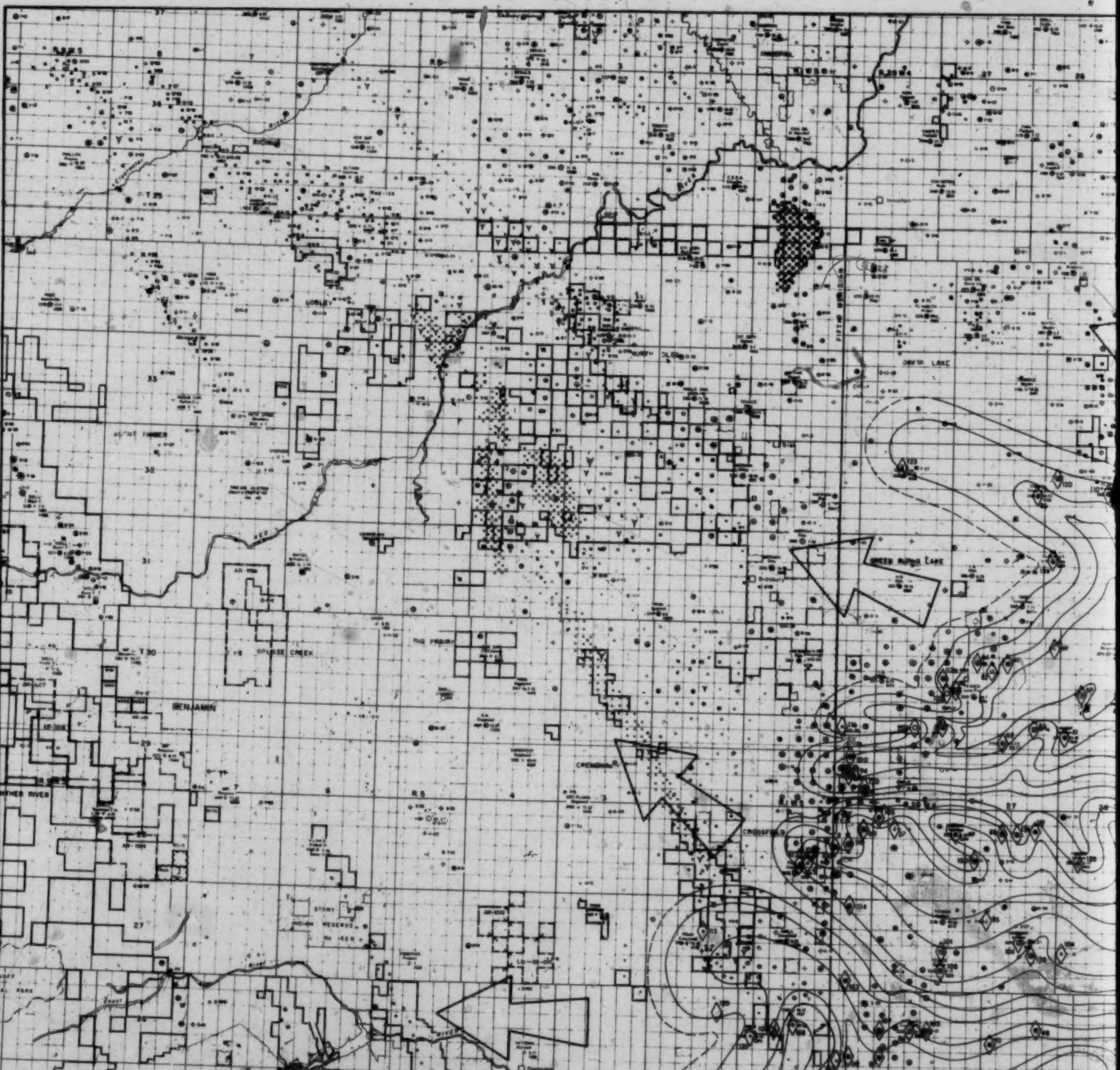
BEARPAW FORMATION

South Central Alberta

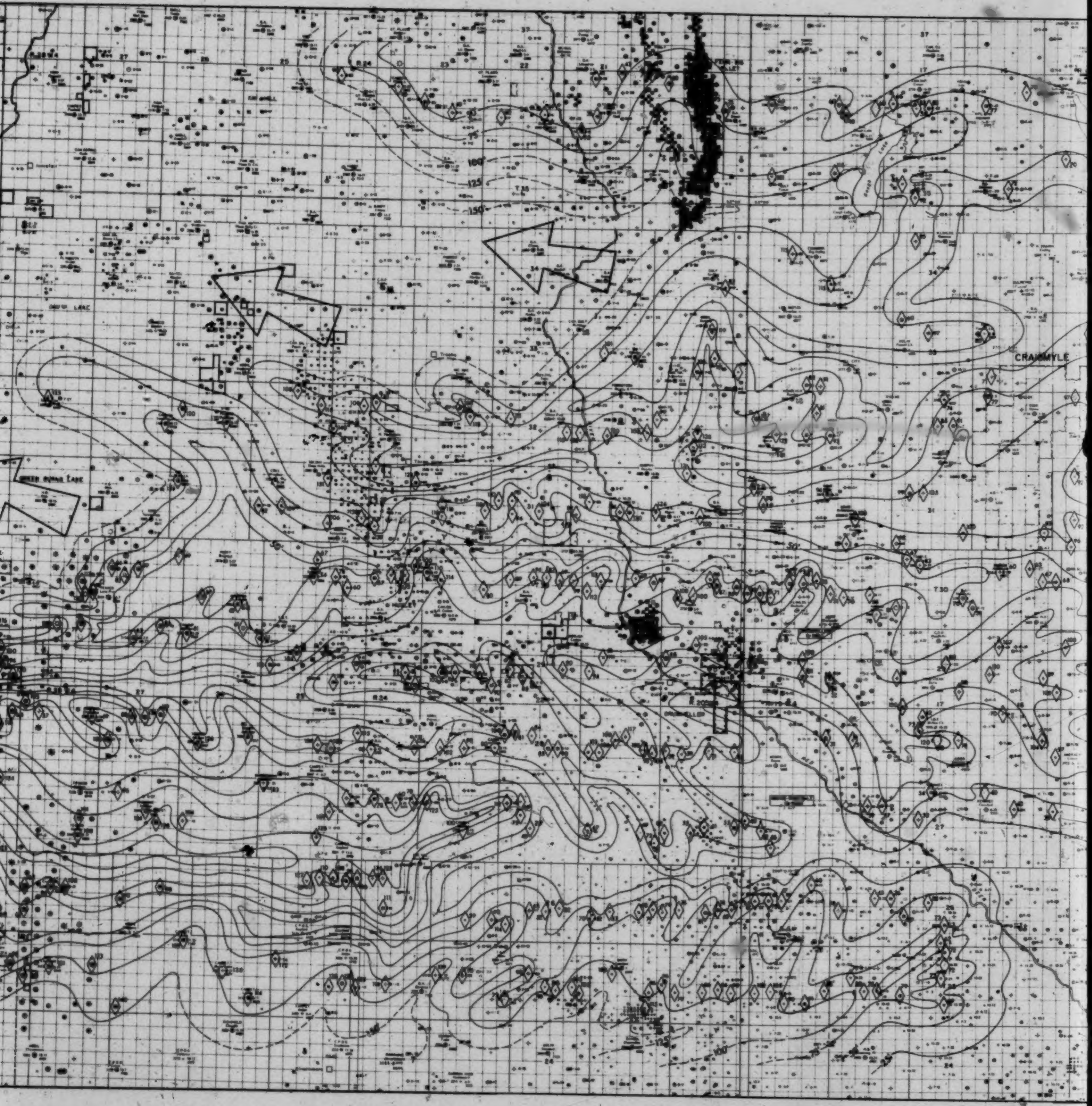
By Antoine G.E. Habib University of Alberta, 1981.

Scale: 1" = 32,000'

3 OF 3


37
36
35
33
32
31
T 30
29
27
24
R 5
3
27
26
FIFTH MERIDIAN
DAVID LAKE
BENJAMIN
CREEK
CROSSFIELD
CALGARY
STORY
INDIAN RESERVE
JUMPING POUND
RIVER

1 OF


CRAIGMYLE
T 30
75
100
125
150
50

2 OF

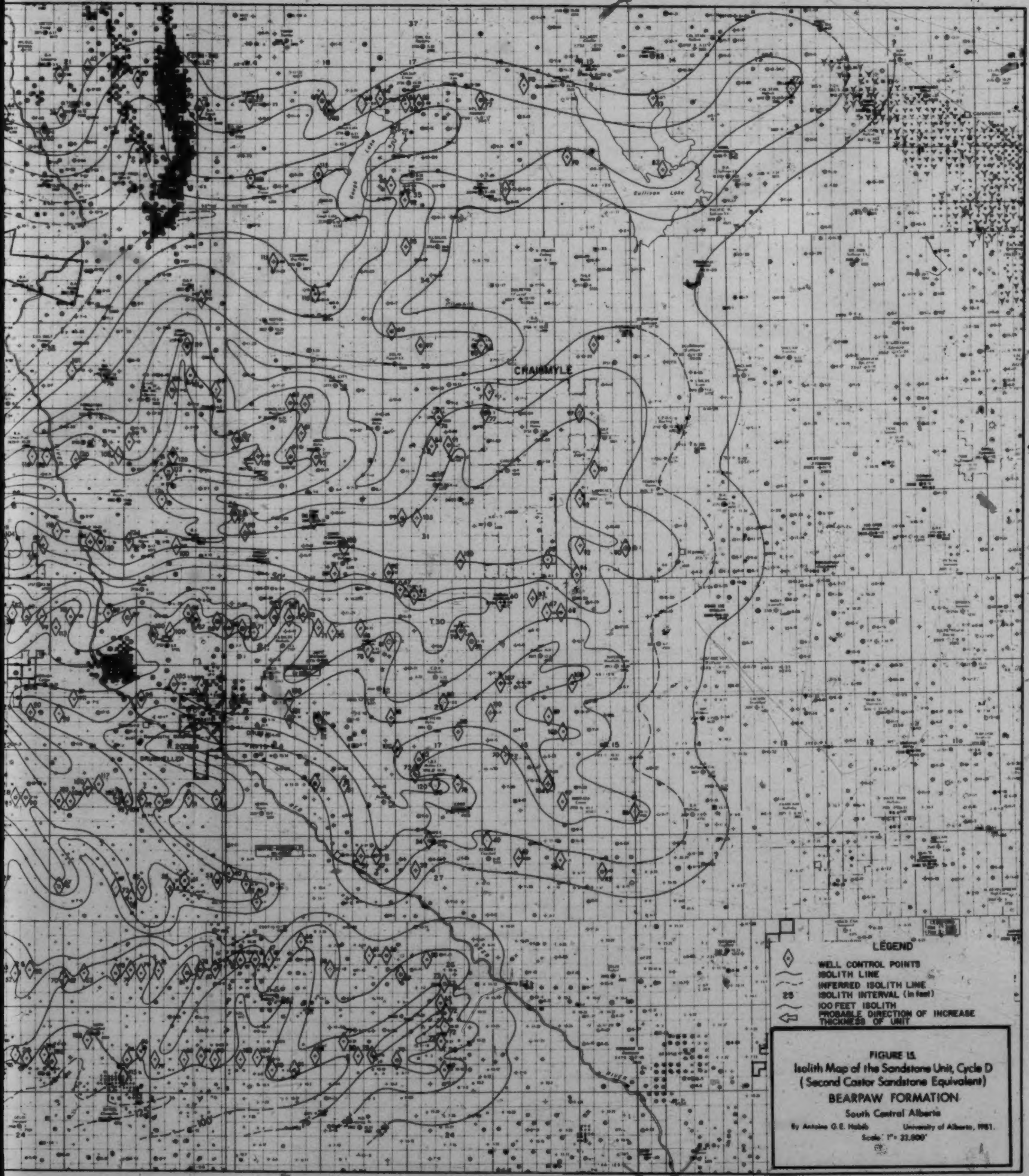
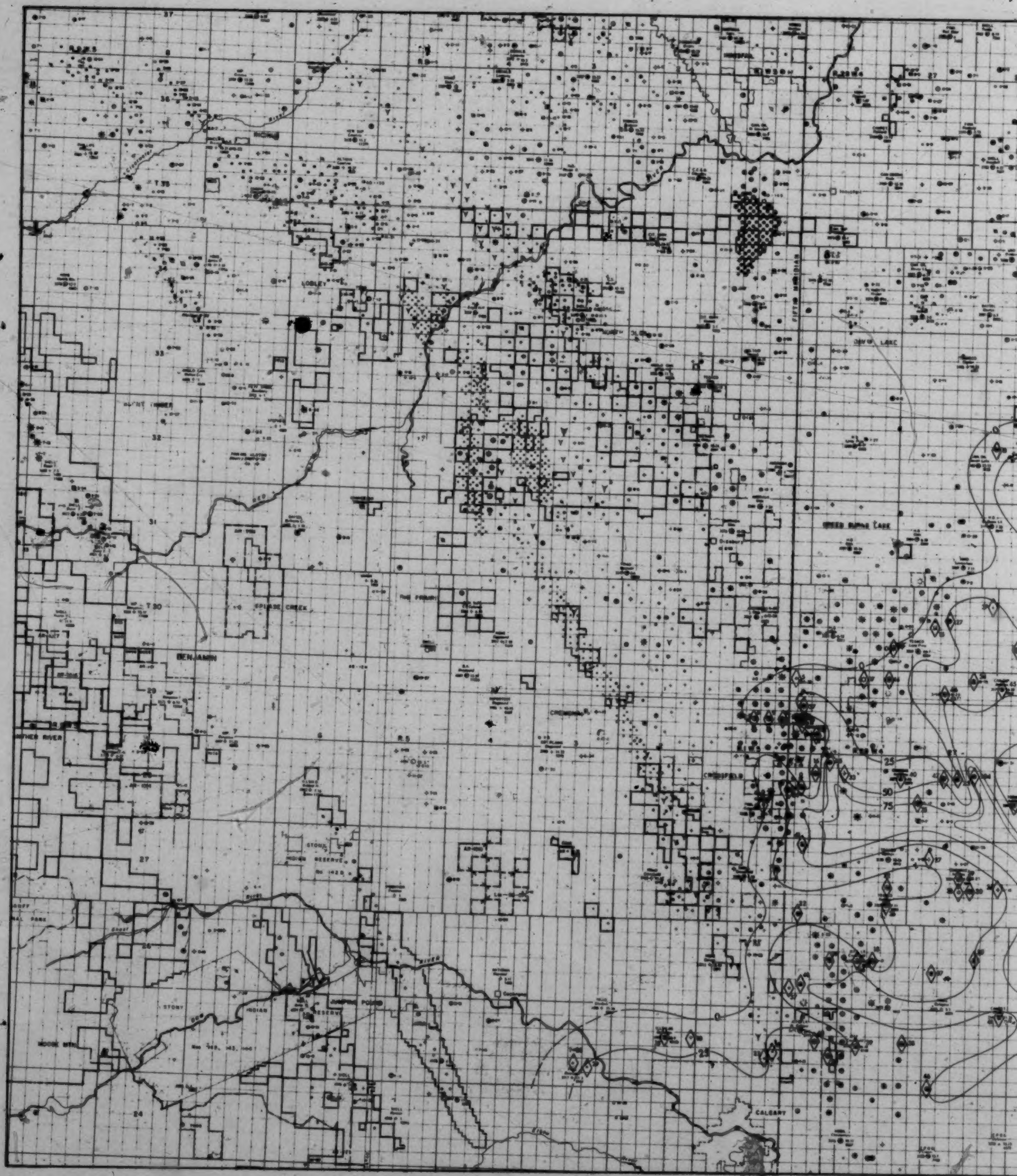
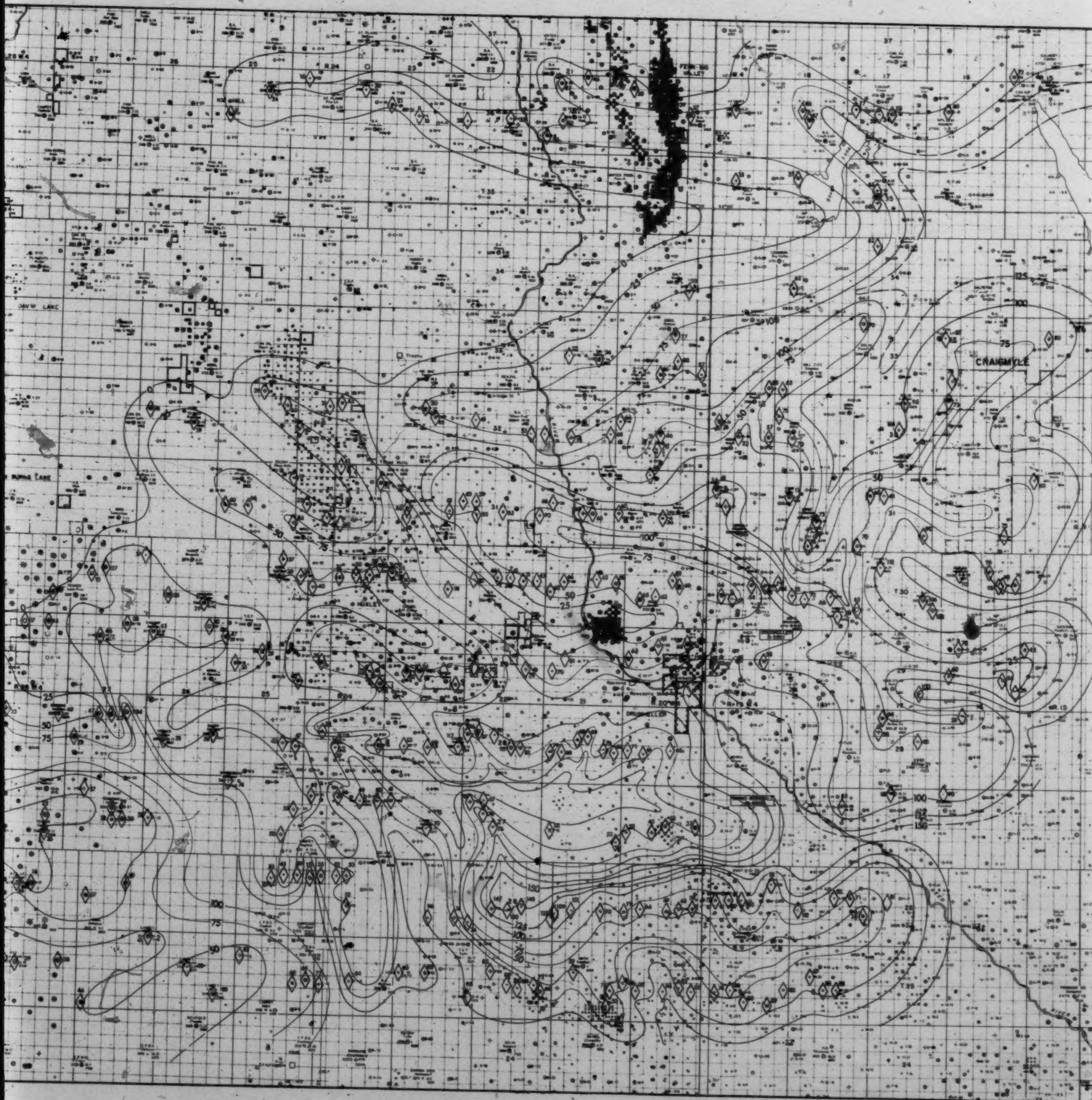

CRAIGMYLE
Sullivan Lake
T.30
DRUMHELLER
LEGEND
WELL CONTROL POINTS
ISOLITH LINE
INFERRED ISOLITH LINE
25 ISOLITH INTERVAL (in feet)
100 FEET ISOLITH
PROBABLE DIRECTION OF INCREASE THICKNESS OF UNIT

FIGURE 15.
Isolith Map of the Sandstone Unit, Cycle D
(Second Castor Sandstone Equivalent)
BEARPAW FORMATION
South Central Alberta
By Antoine G.E. Habib University of Alberta, 1981.
Scale: 1" = 22,600'

3OF3


37
36
T 35
RIVER
34
LOBLEY
33
32
31
DEER
T 30
SPRUCE CREEK
BENJAMIN
29
THER RIVER
R.5
27
STONY
INDIAN RESERVE
No 142 B
GHOST
26
RIVER
STONY
INDIAN
RESERVE
JUMPING POUND
MOOSE MTN
24
FIFTH MERIDIAN
LAKE
CREMONA
CROSSFIELD
CALGARY
25
50
75
0
25
27

1 OF


R 24
T 35
CRAIGMYLE
T 30
R 20
R 13
25
50
75
100
125
150

2 OF

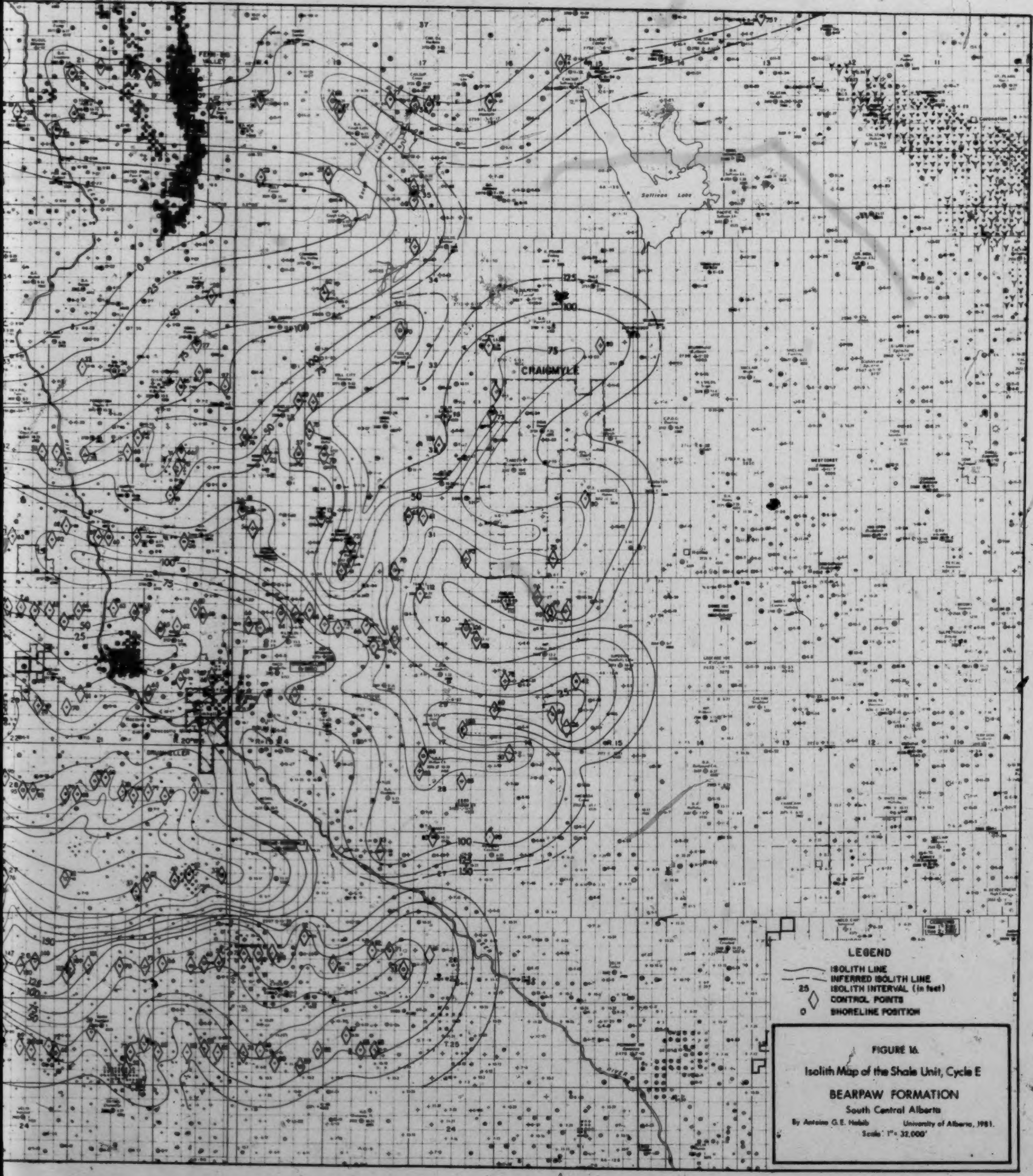

CRAIGMYLE
Sullivan Lake
LEGEND
ISOLITH LINE
INFERRED ISOLITH LINE
25 ISOLITH INTERVAL (in feet)
CONTROL POINTS
0 SHORELINE POSITION

FIGURE 16.

Isolith Map of the Shale Unit, Cycle E

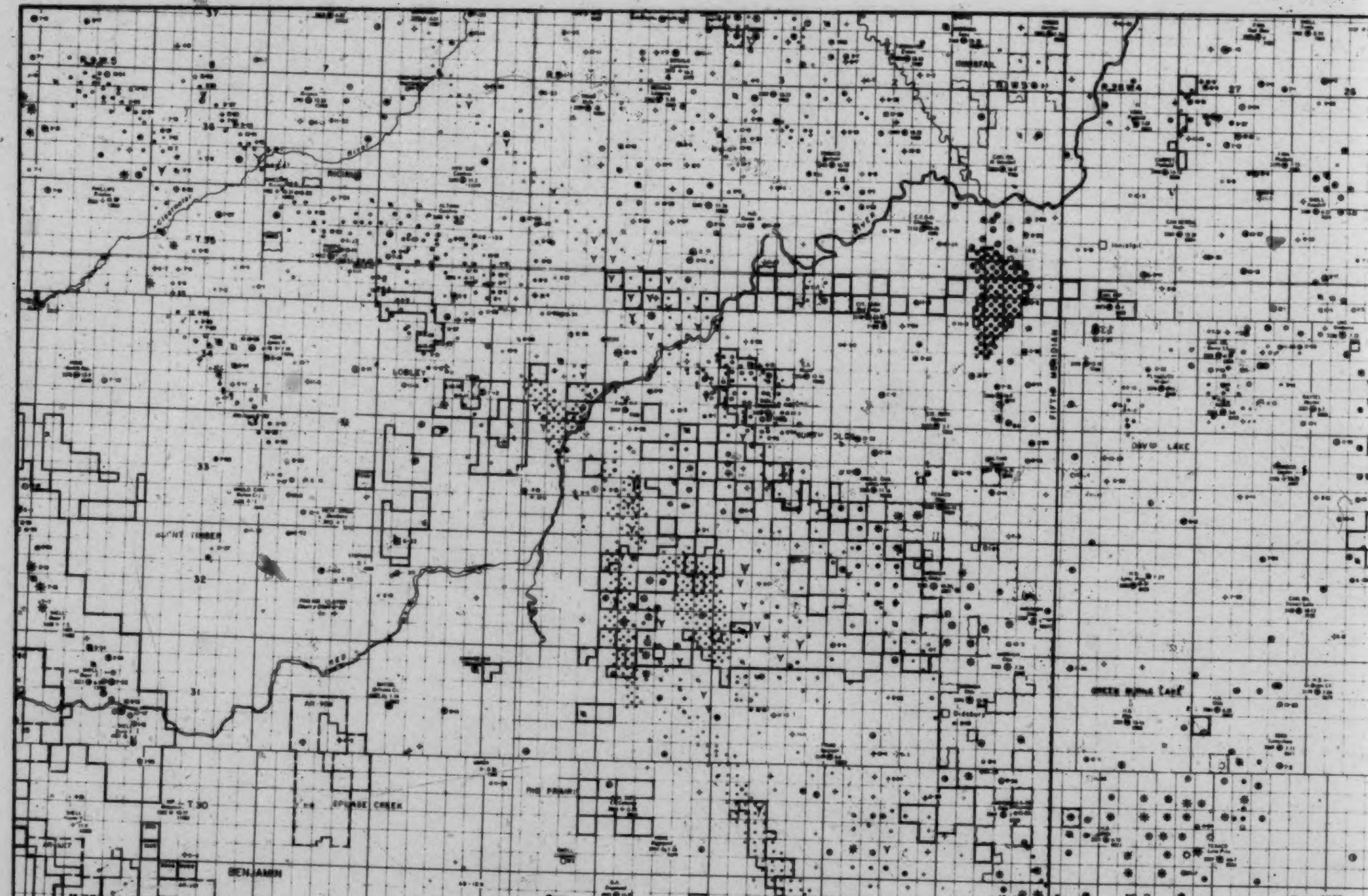
BEARPAW FORMATION

South Central Alberta

By Antoine G.E. Habib University of Alberta, 1981.

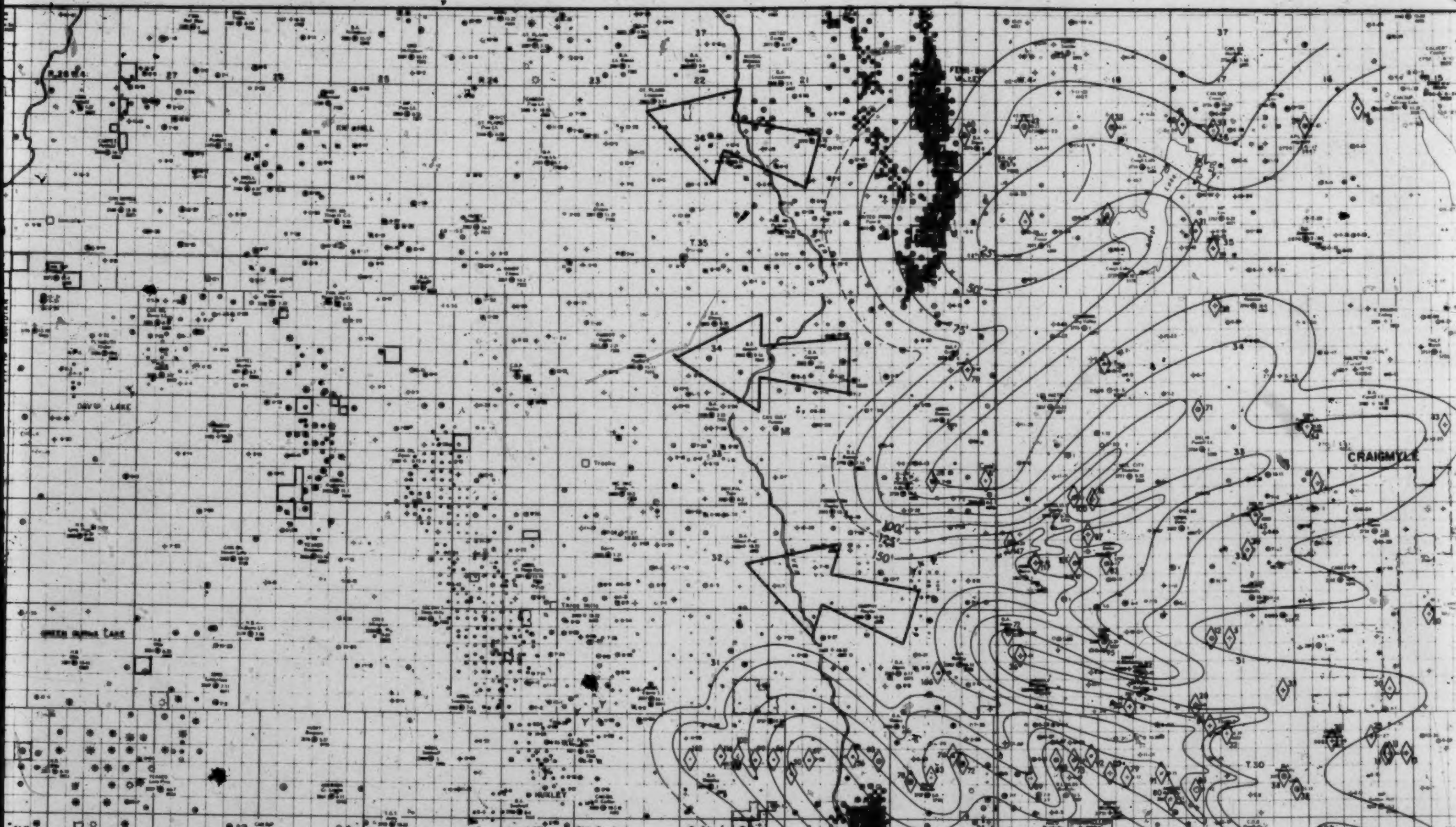
Scale: 1" = 32,000'

3OF 3



T.35
33
32
31
T.30
29
27
24
R.5
7
6
4
3
2
27
BENJAMIN
SPRUCE CREEK
CREMONA
CROSSFIELD
CALGARY
STORY
INDIAN RESERVE
STONY
INDIAN
RESERVE
JUMPING POUND
FIFTH MERIDIAN
DAVID LAKE
RED
RIVER
BOW

1 OF


DAVID LAKE
GREEN GRASS LAKE
CRAIGMYLE
DRUMHELLER
HUXLEY
T.35
T.30
T.29
R.24
37
35
34
33
32
31
29
28
27
26
25
24
23
22
21
20
19
18
17
16
25'
50'
75'
100'
125'
150'

2 OF

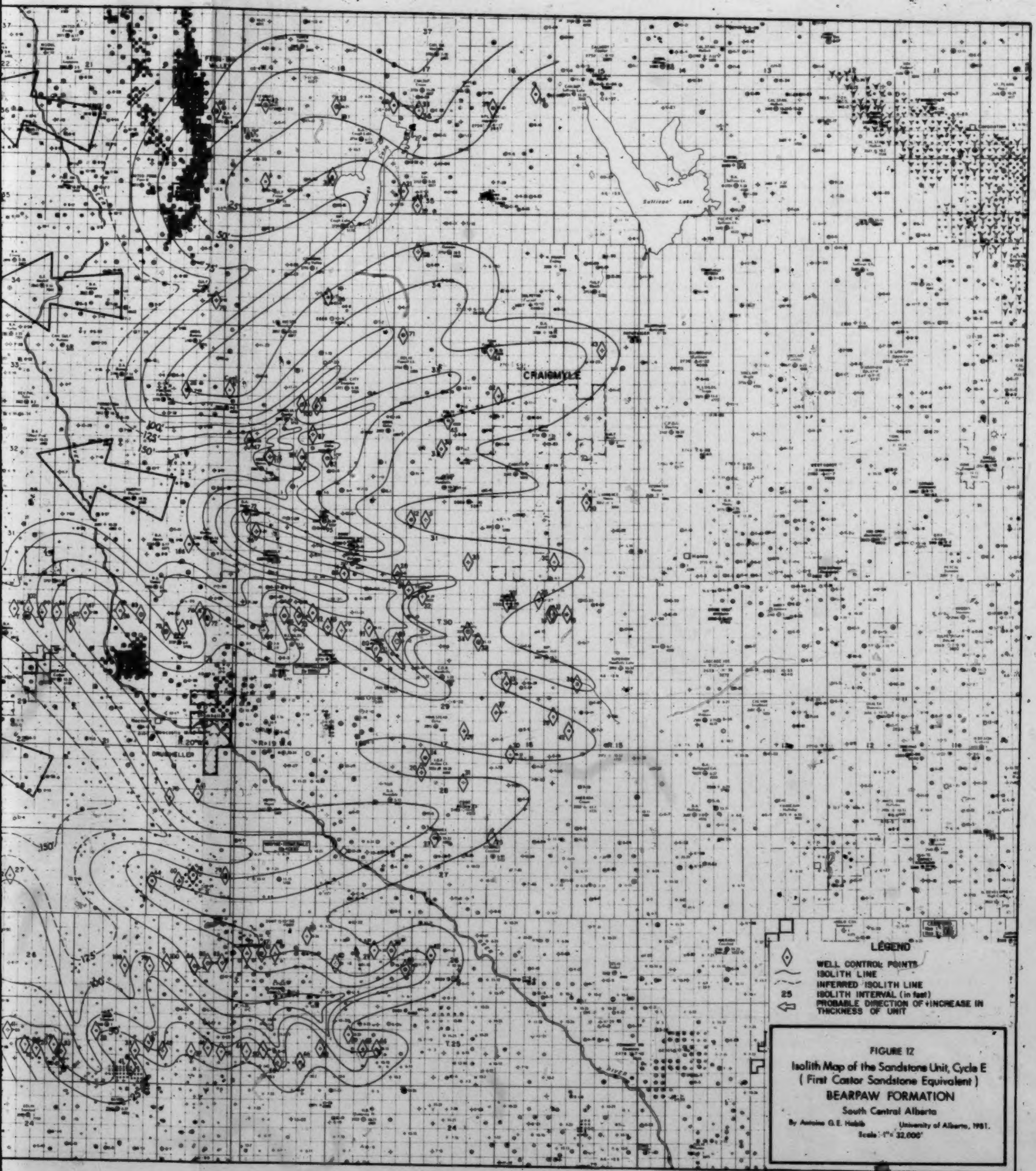

CRAIGMYLE
Sullivan Lake
DRUMHELLER
25
50
75
100
125
150
175
LEGEND
WELL CONTROL POINTS
ISOLITH LINE
INFERRED ISOLITH LINE
25
ISOLITH INTERVAL (in feet)
PROBABLE DIRECTION OF INCREASE IN THICKNESS OF UNIT

FIGURE 12

Isolith Map of the Sandstone Unit, Cycle E
(First Castor Sandstone Equivalent)

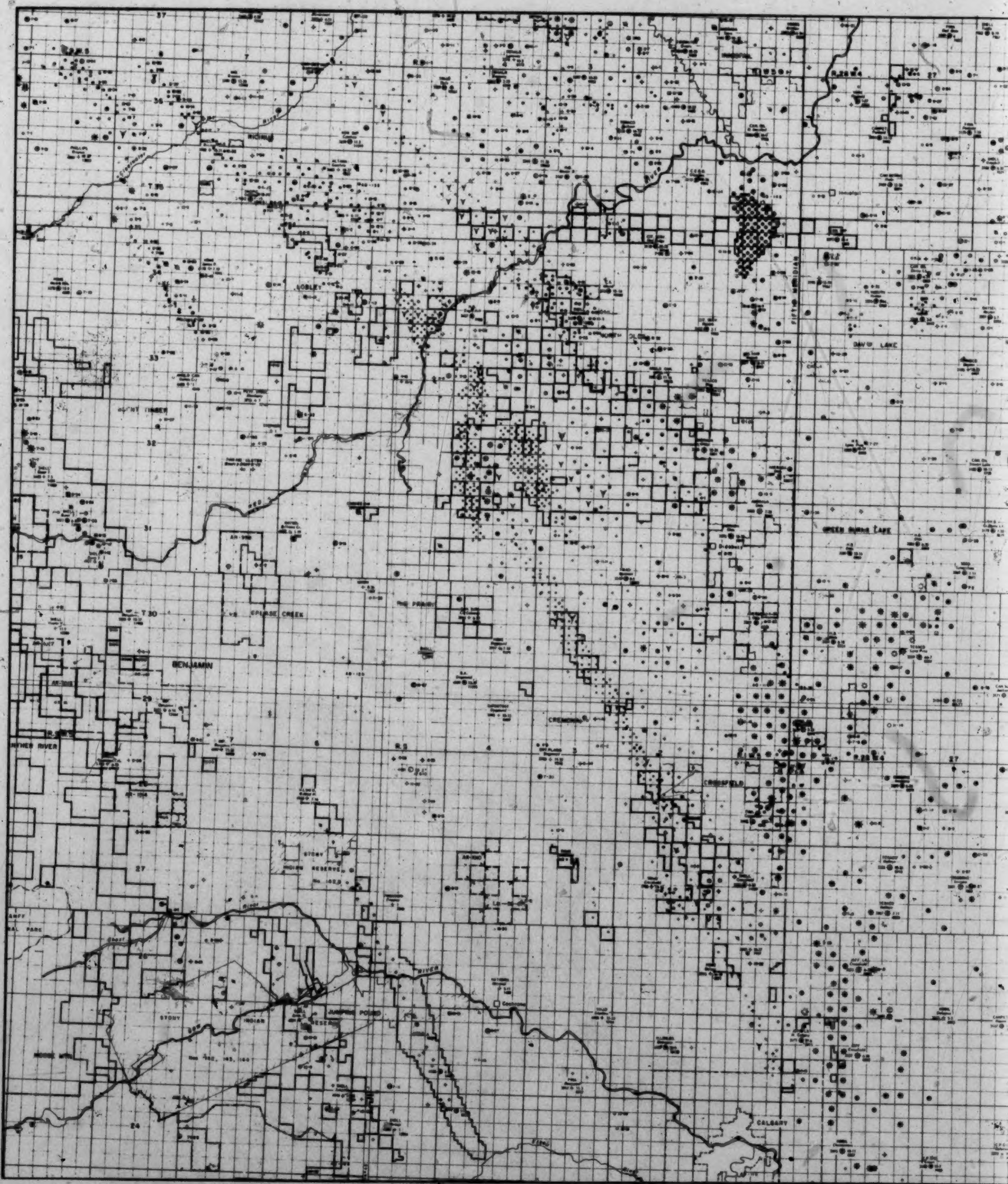
BEARPAW FORMATION

South Central Alberta

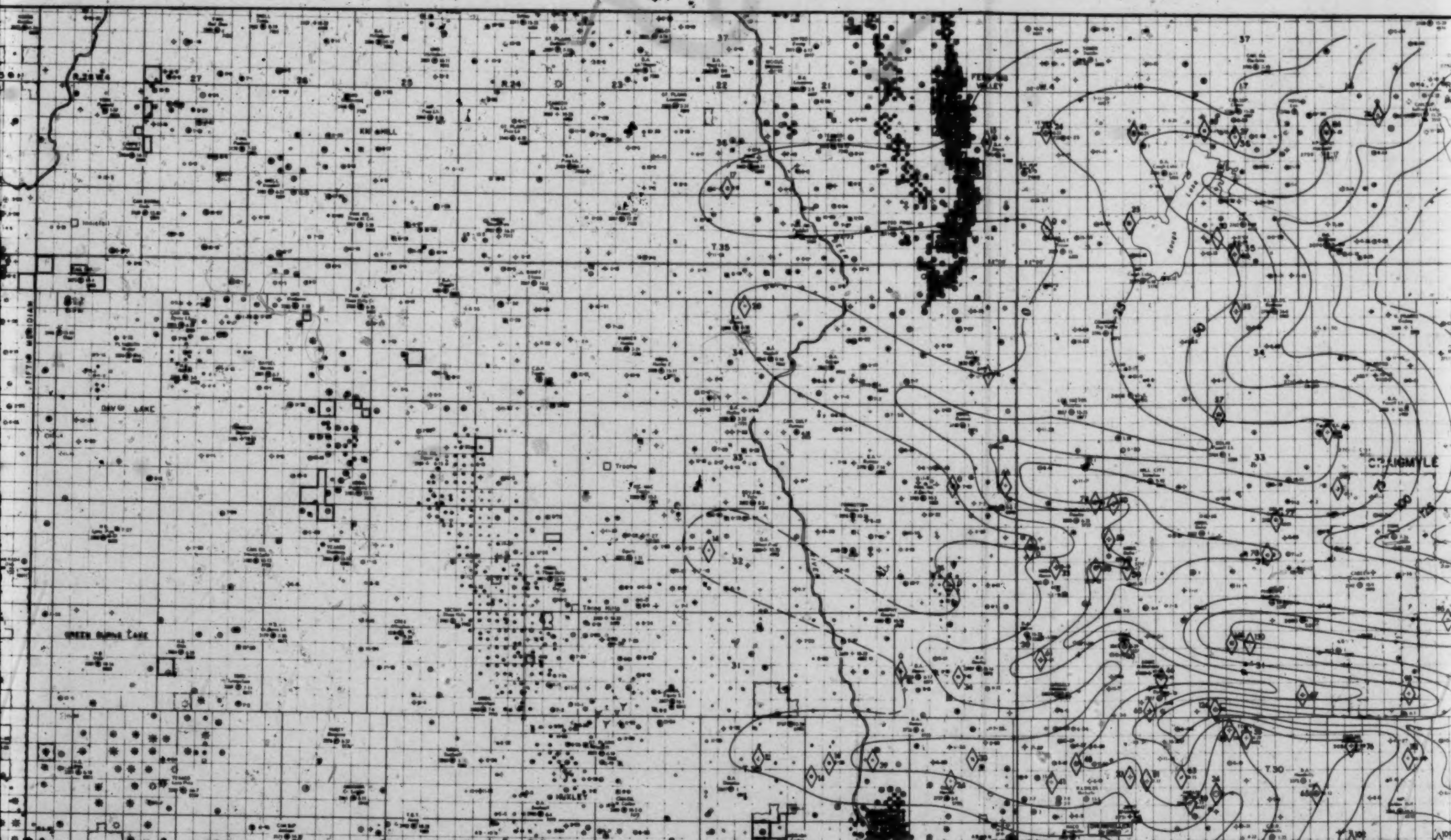
By Antoine G.E. Habib University of Alberta, 1981.

Scale: 1" = 32,000'

3 OF 3


37
36
T 30
33
32
31
29
27
24
BENJAMIN
SPURSE CREEK
THE PRAIRIE
CREMONA
CROSSFIELD
CALGARY
STONY
INDIAN RESERVE
No. 142 B
R 5
27
RIVER
GHOST
BANFF
NAL PARK
FIFTH MERIDIAN
DAVEY LAKE
ALBERTA LAKE
6
4

1 OF


FIFTH MERIDIAN
CRAIGMYLE
DRUMHELLER
HUXLEY
T.35
T.30
R.24
25
50
75
100
125
150

2 OF

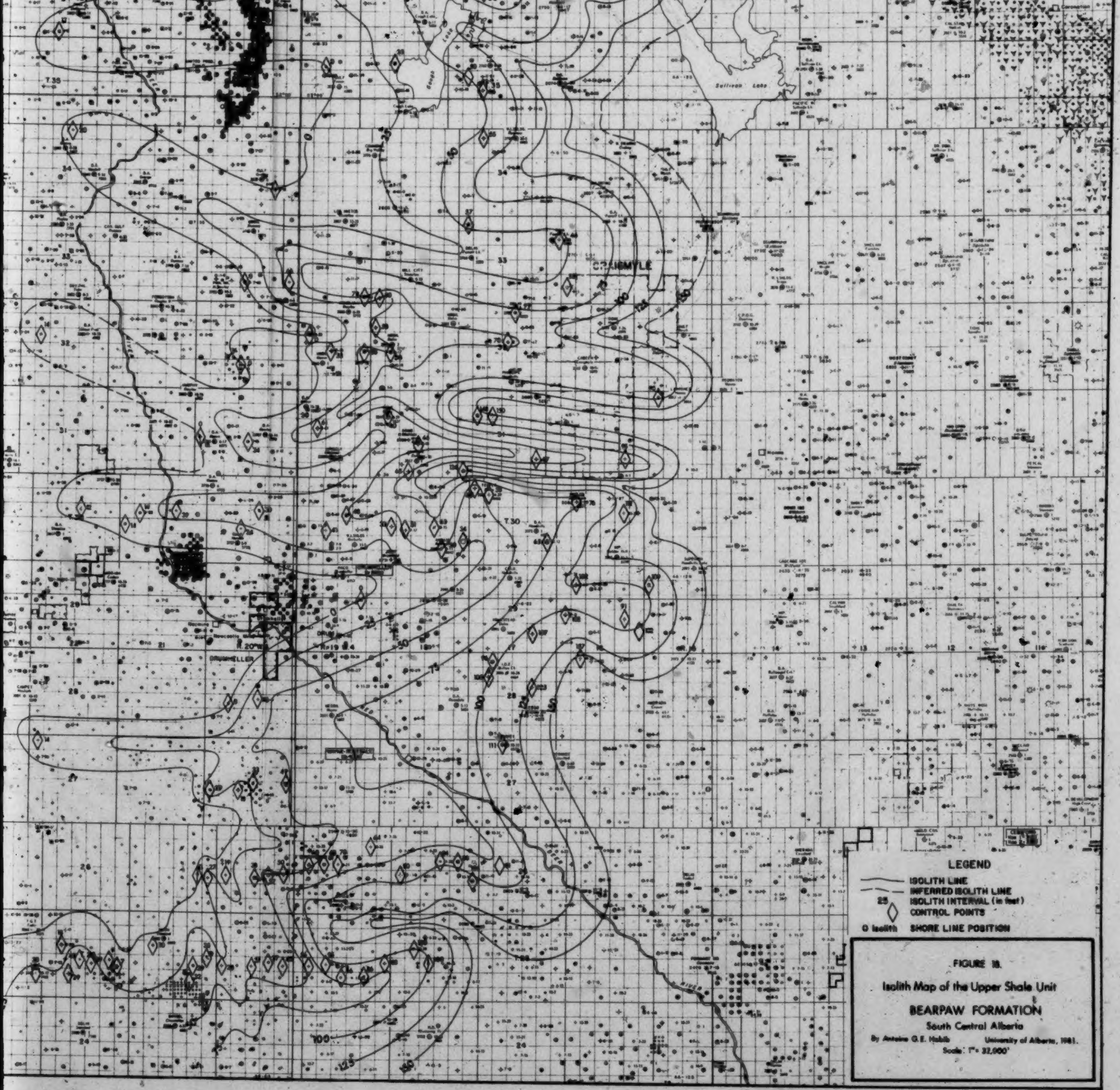

CRAIGMYLE
DRUMHELLER
Sullivan Lake
Gough Lake
T.30
LEGEND
ISOLITH LINE
INFERRED ISOLITH LINE
25 ISOLITH INTERVAL (in feet)
CONTROL POINTS
0 Isolith SHORE LINE POSITION

FIGURE 18.

Isolith Map of the Upper Shale Unit

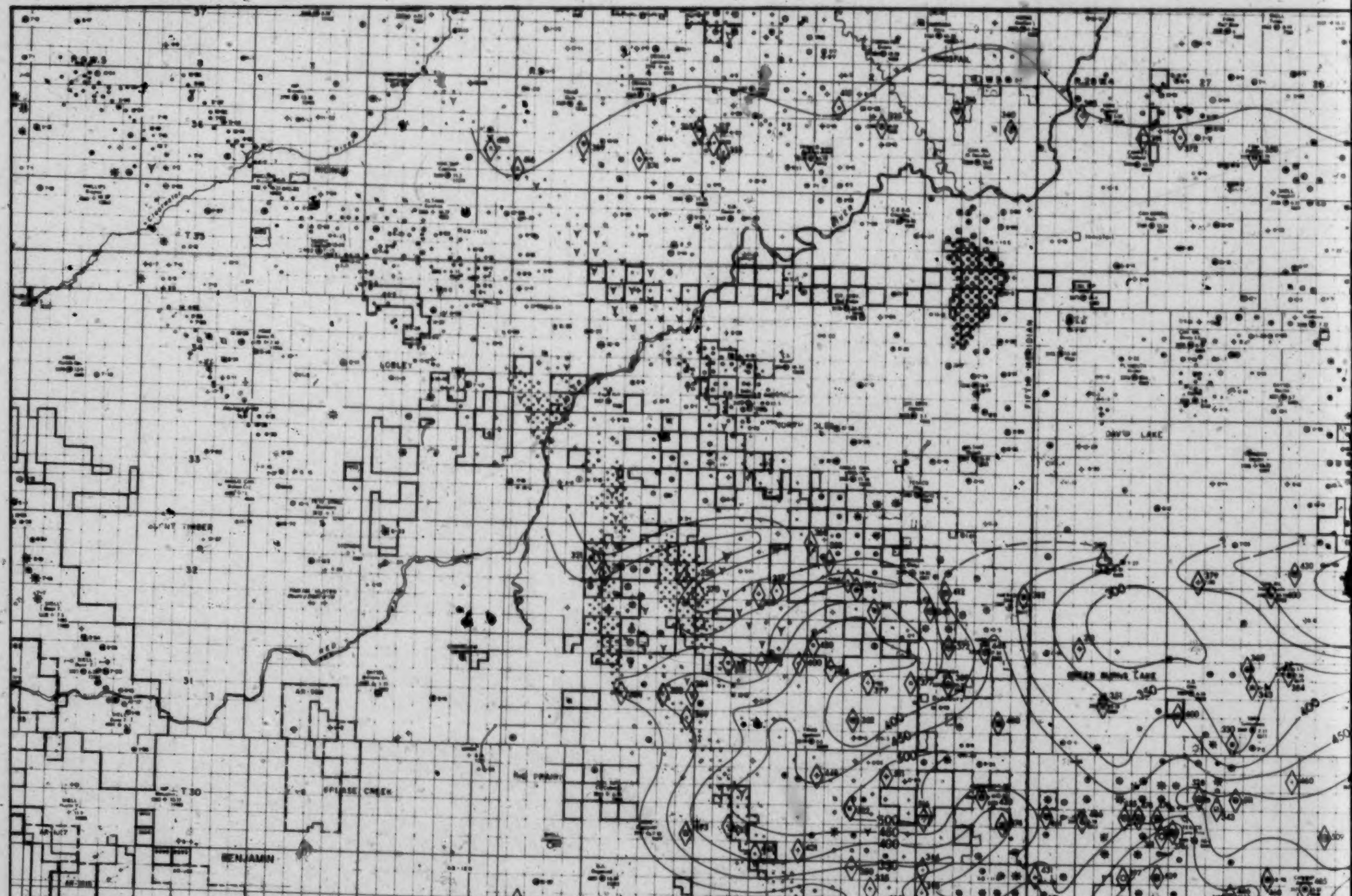
BEARPAW FORMATION

South Central Alberta

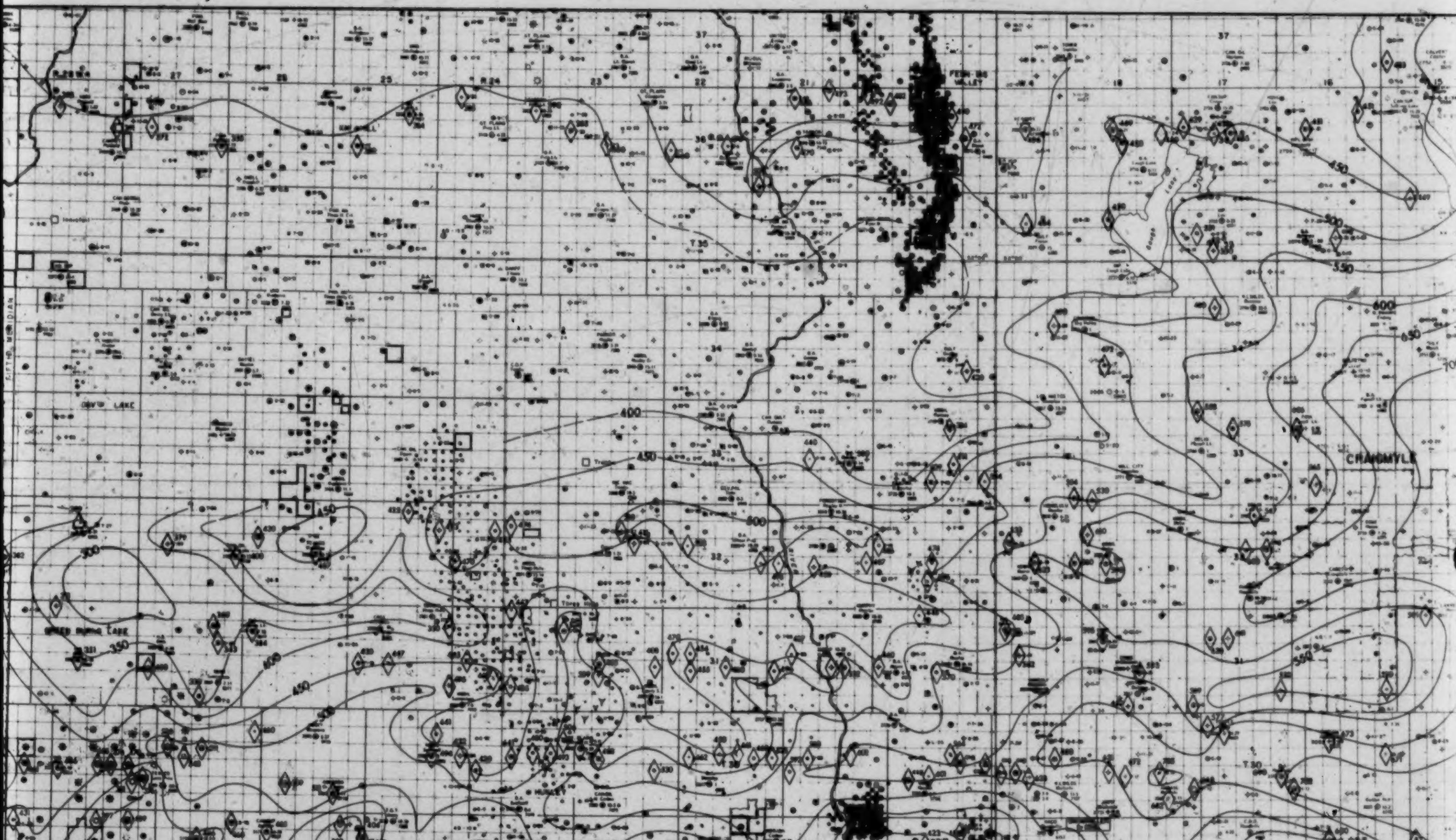
By Antoine G.E. Habib University of Alberta, 1981.

Scale: 1"= 32,000'

3OF 3


BENJAMIN
FIFTH MERIDIAN
CALGARY
STONY
INDIAN
MOOSE MTN
T 30
300
350
400
450
500

1 OF


CRAIGMYLE
DRUMHELLER
T.30
R.24
400
450
500
550
600
650
700
350
300

2 OF

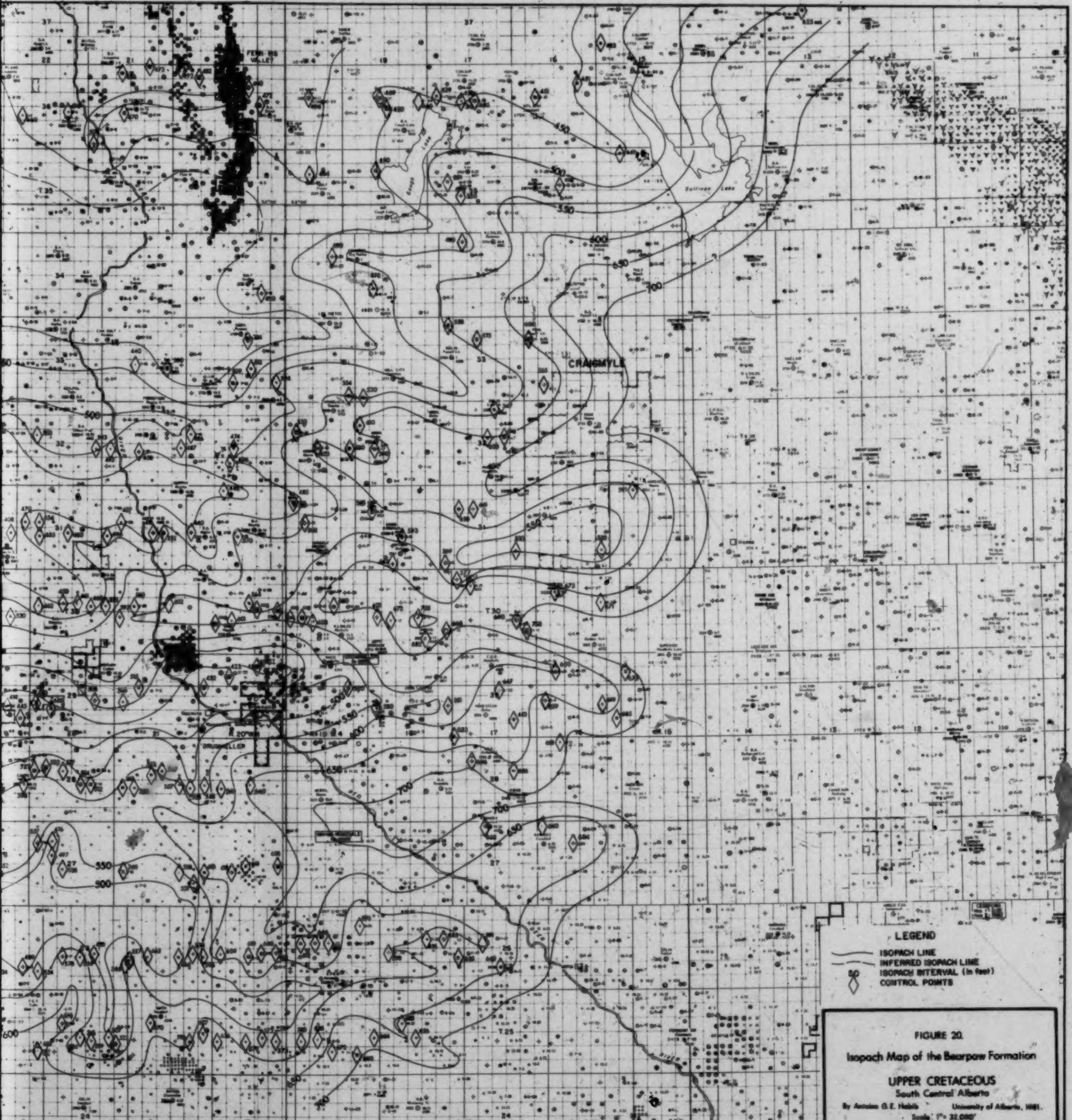

LEGEND
ISOPACH LINE
INFERRED ISOPACH LINE
50
ISOPACH INTERVAL (in feet)
CONTROL POINTS
CRAIGMYLE
DRUMHELLER
Sullivan Lake
450
500
550
600
650
700
350
T.30
T.25
R.20

FIGURE 20.

Isopach Map of the Bearpaw Formation

UPPER CRETACEOUS

South Central Alberta

By Antoine G.E. Habib University of Alberta, 1981.

Scale: 1" = 32,000'

3oF 3